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Graham et al.

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(54) DRILL BIT CUTTER ELEMENTS AND DRILL BITS INCLUDING SAME

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(73) Assignee: **NATIONAL OILWELL VARCO, L.P.**, Houston, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 37 days.

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PCT Pub. Date: **Mar. 19, 2020**

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(51) **Int. Cl.**

E21B 10/567	(2006.01)
E21B 10/55	(2006.01)
E21B 10/43	(2006.01)

(52) **U.S. Cl.**
CPC ***E21B 10/5673*** (2013.01); ***E21B 10/43*** (2013.01); ***E21B 10/55*** (2013.01)

(58) **Field of Classification Search**
CPC E21B 10/5673; E21B 10/5676
See application file for complete search history.

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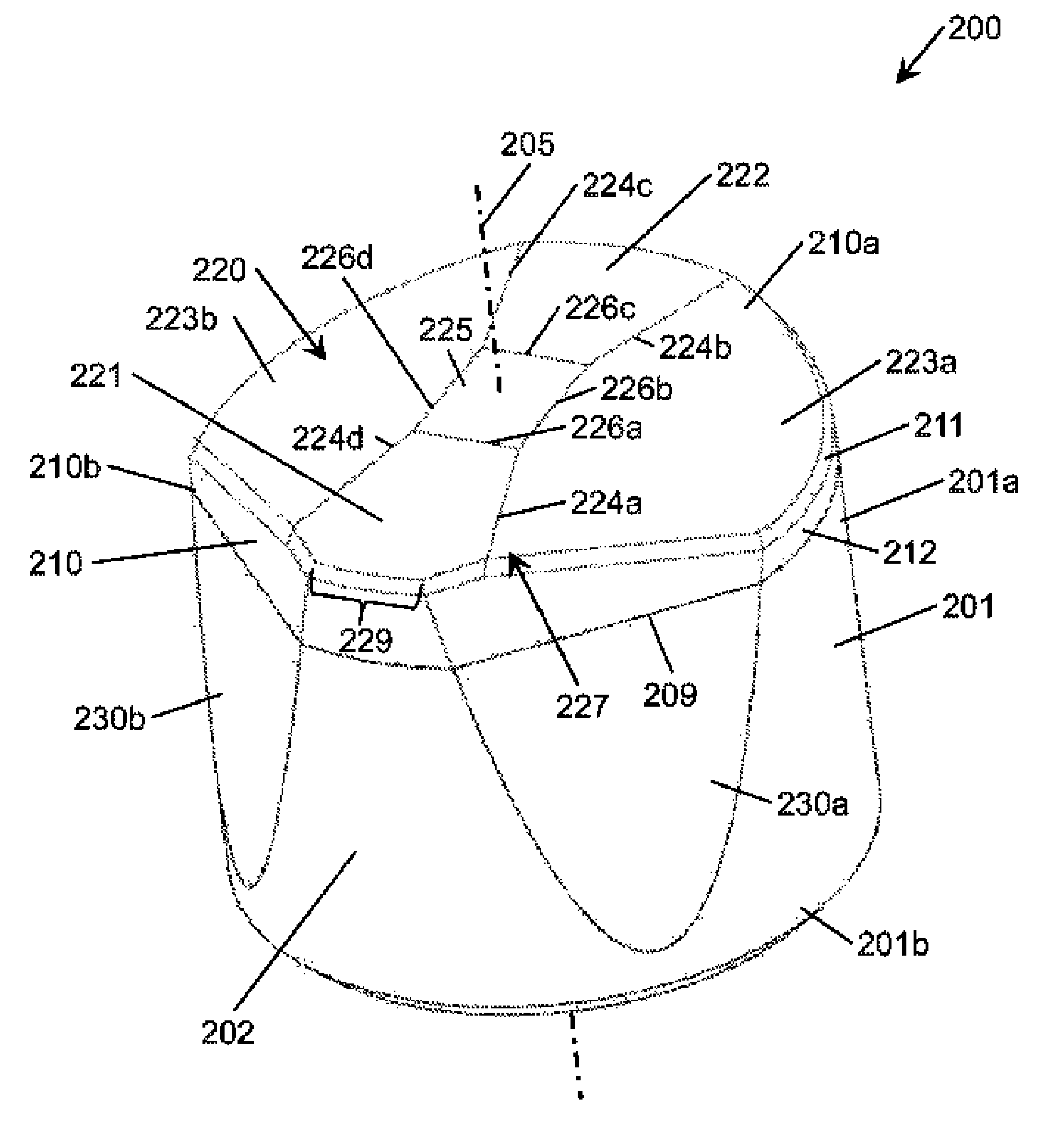
Primary Examiner — Blake Michener
(74) *Attorney, Agent, or Firm* — Conley Rose, P.C.

(57) ABSTRACT

A cutter element for a drill bit includes a base portion having a central axis, a first end, and a second end. In addition, the cutter element includes a cutting layer fixably mounted to the first end of the base portion. The cutting layer includes a cutting face distal the base portion. The cutting face includes an elongate raised ridge having a first end at a radially outer surface of the cutting layer and a second end at the radially outer surface of the cutting layer. The raised ridge defines a maximum height of the cutter element measured axially from the second end of the base portion to the cutting face. The cutting face also includes a first planar lateral side surface and a second planar lateral side surface. Each planar lateral side surface extends from the raised ridge to the radially outer surface of the cutting layer.

46 Claims, 31 Drawing Sheets



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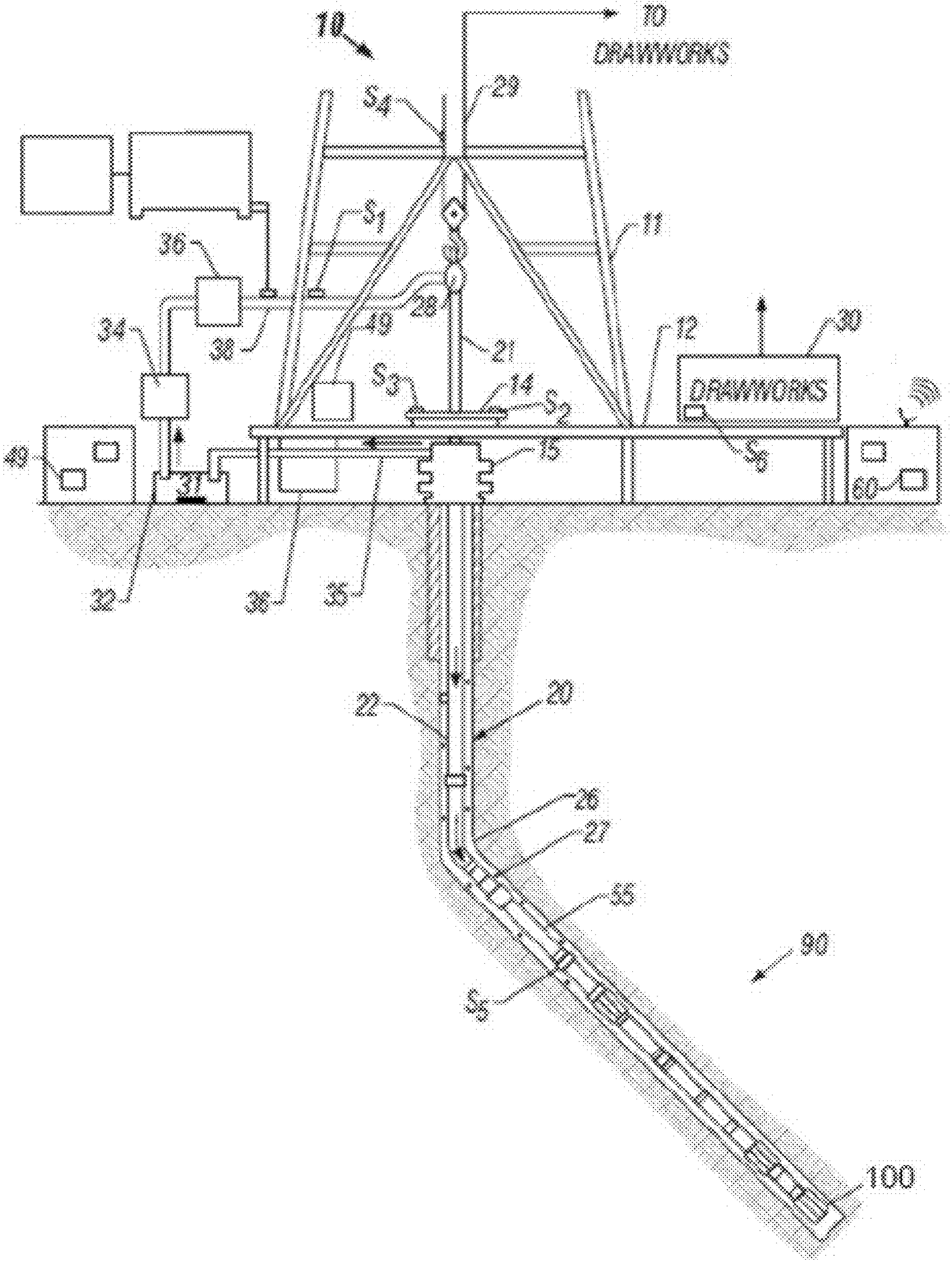
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S_5
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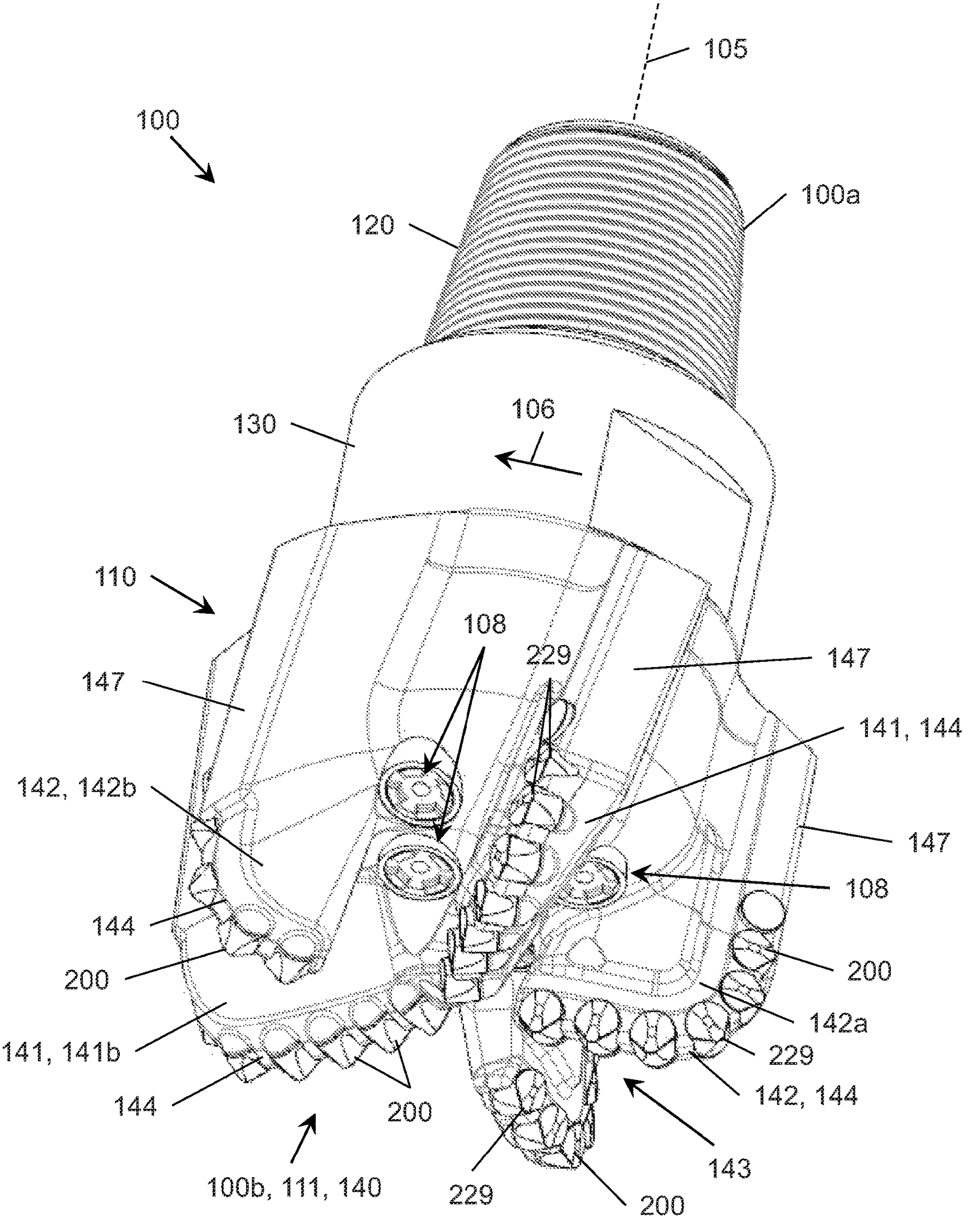
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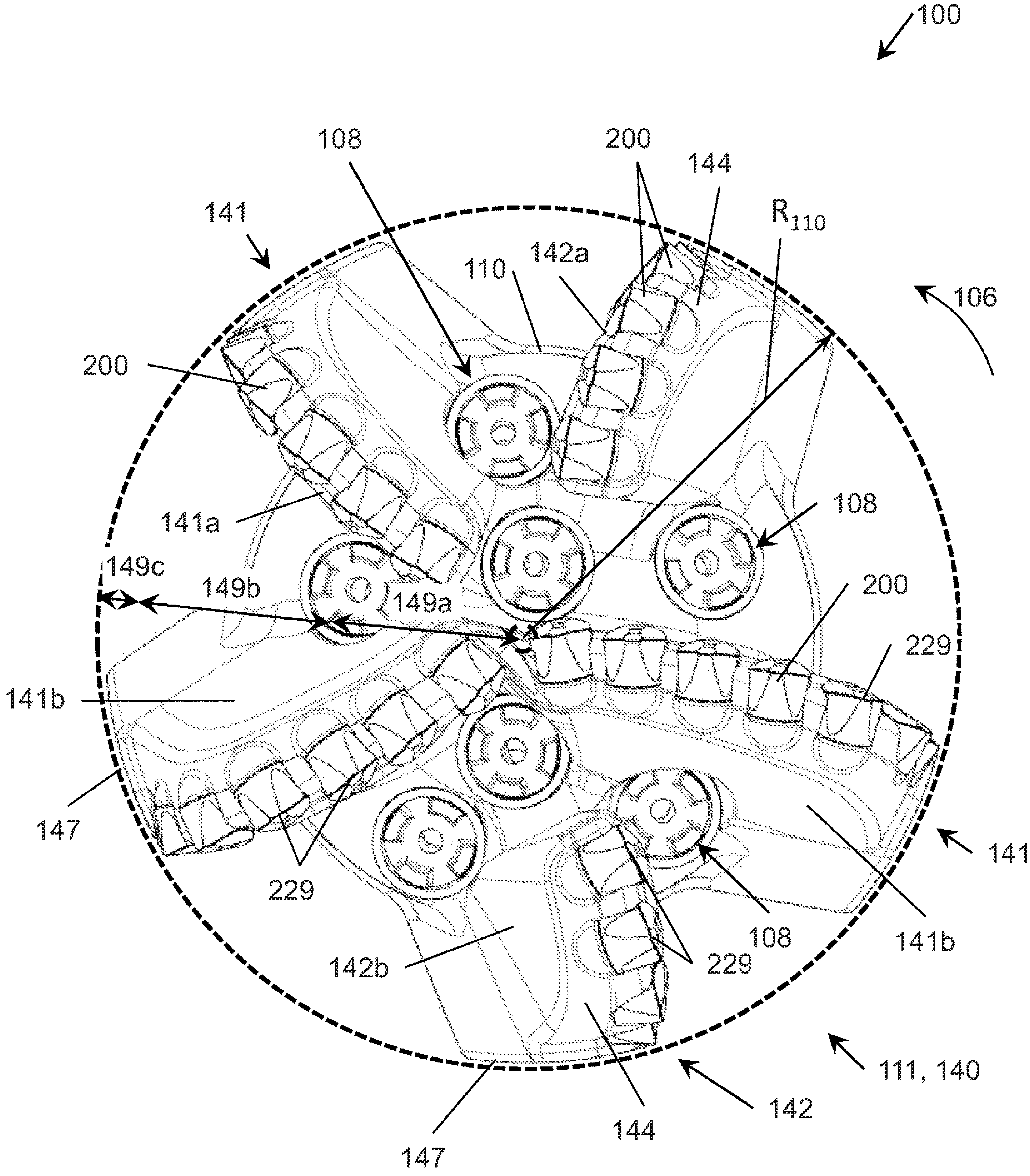
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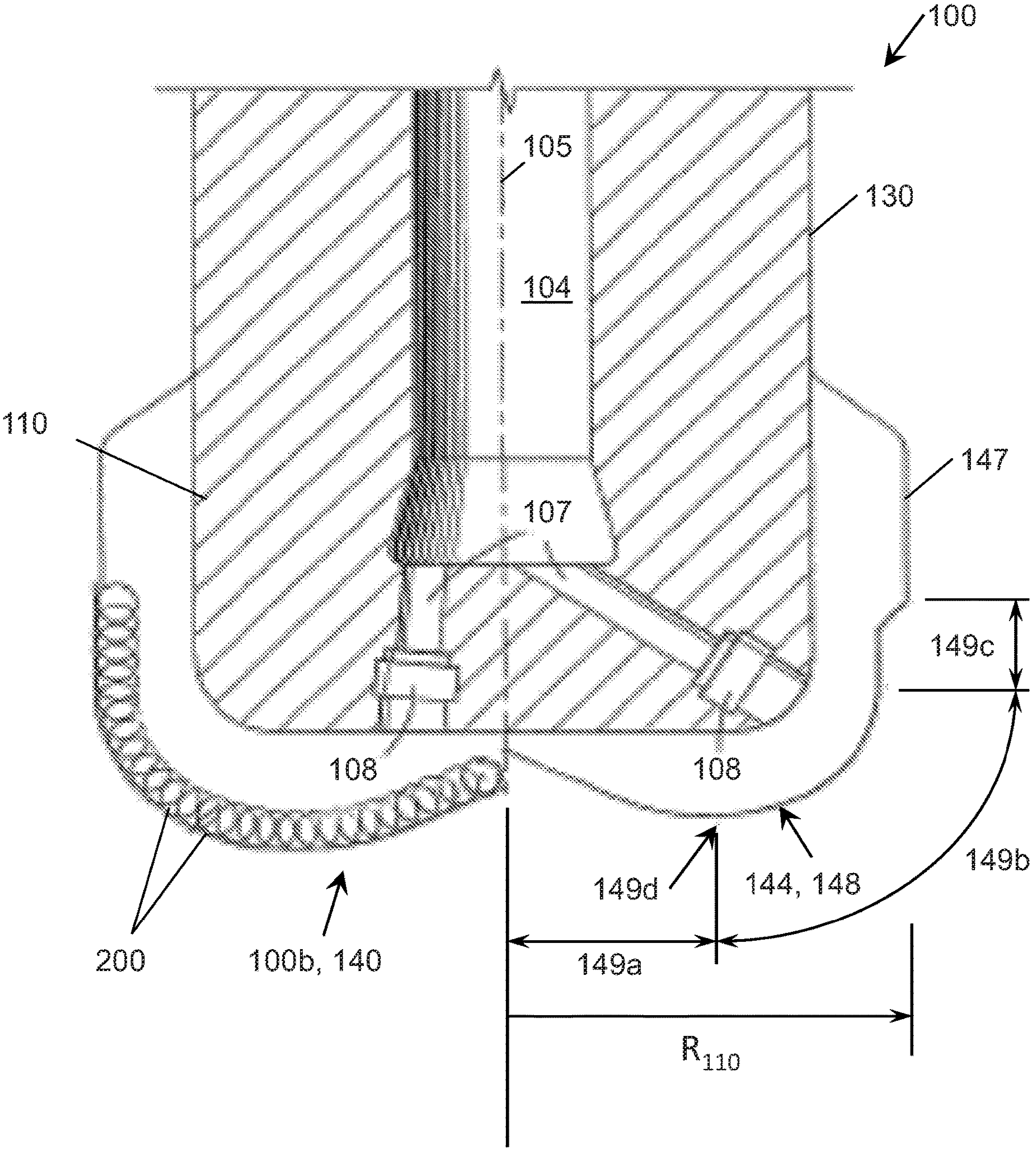
Figure 3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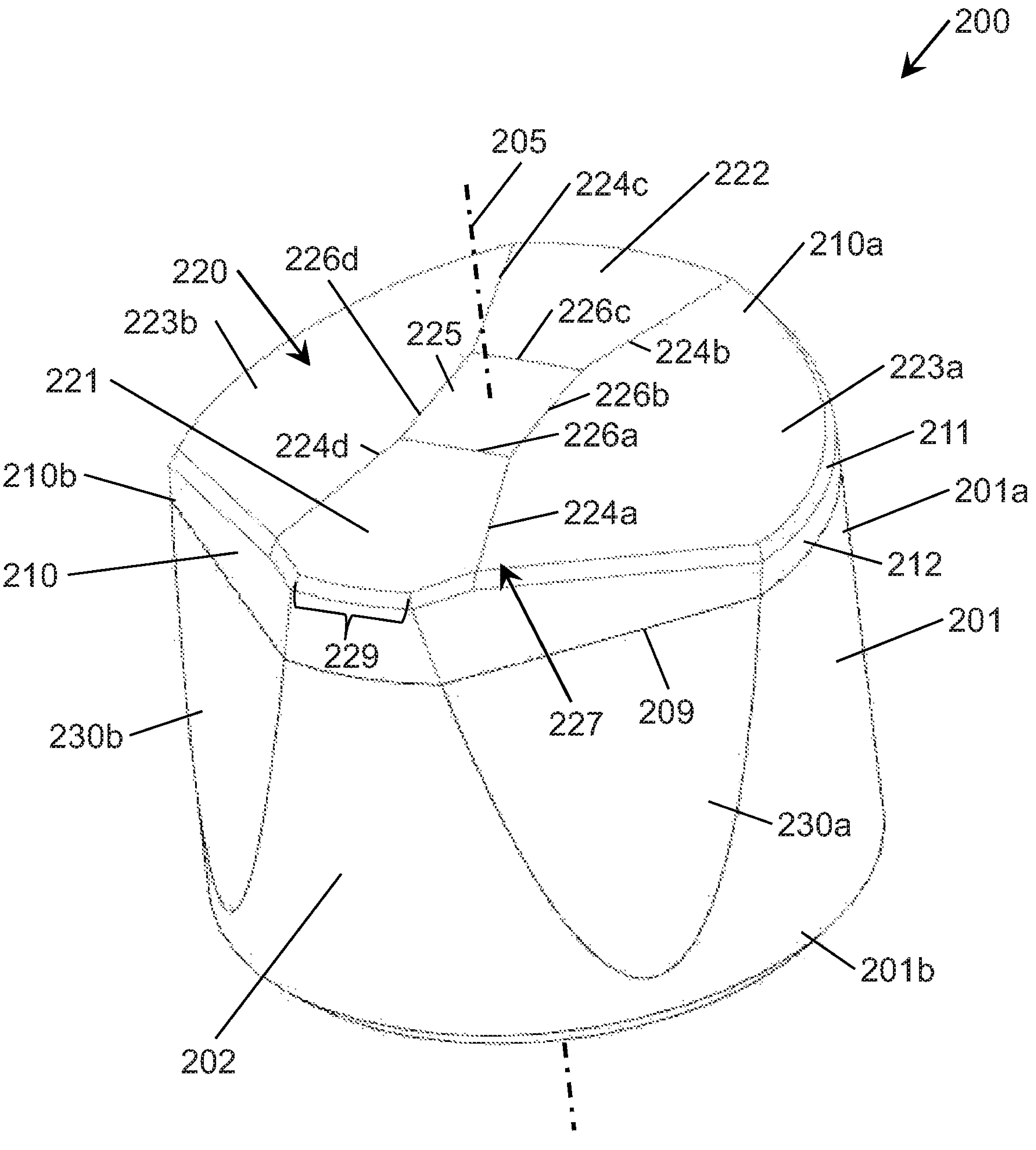
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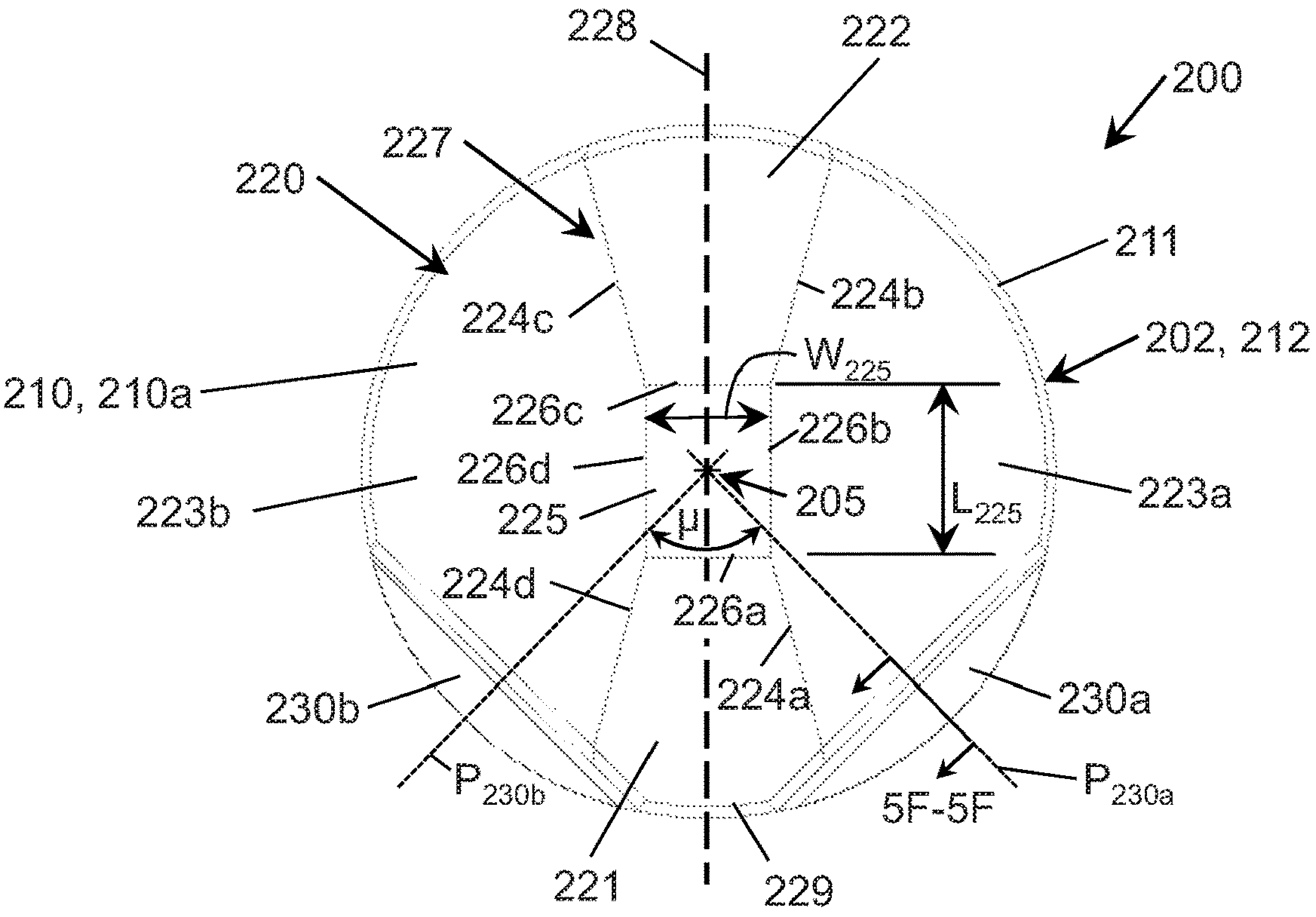
Figure 5A



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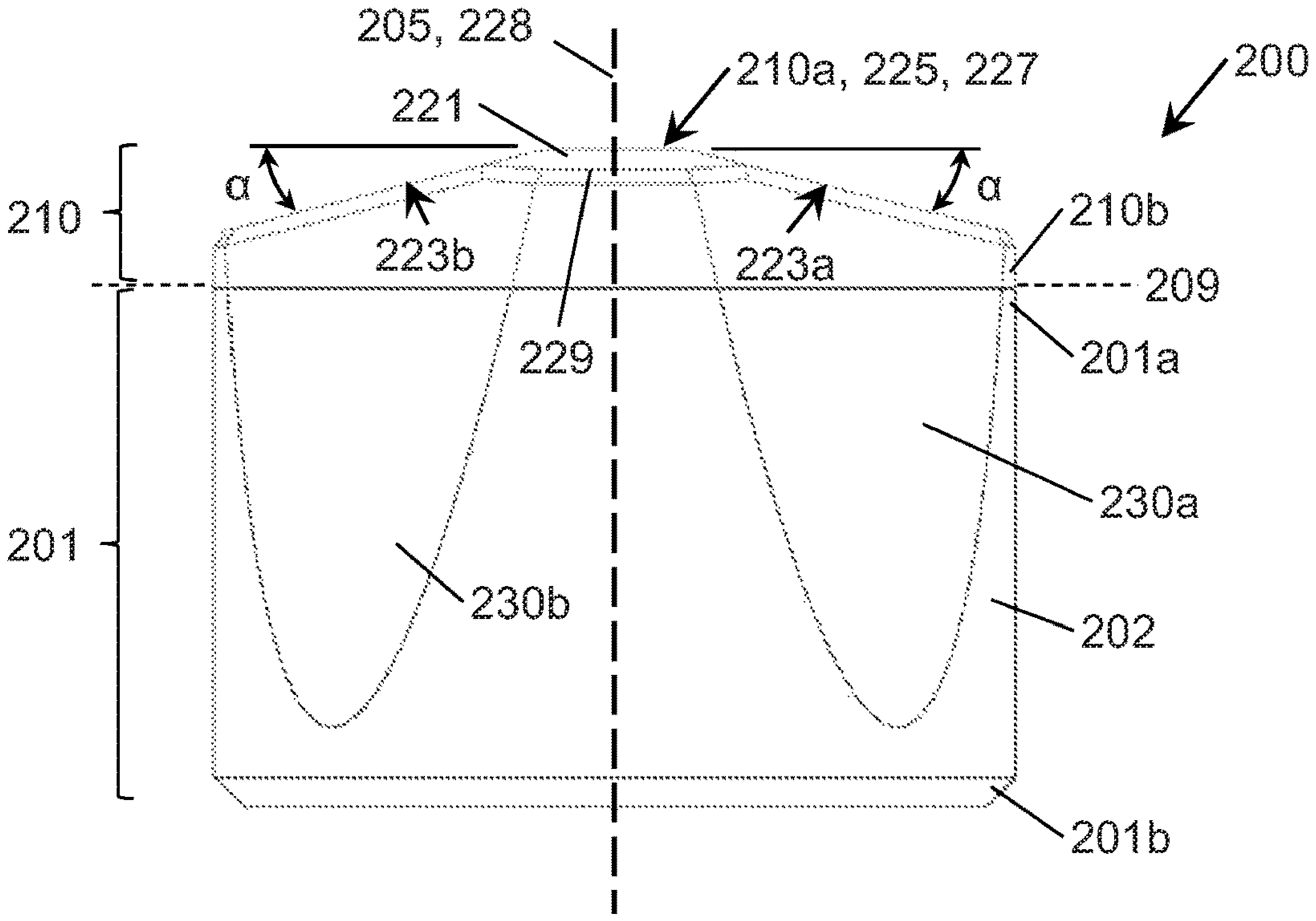

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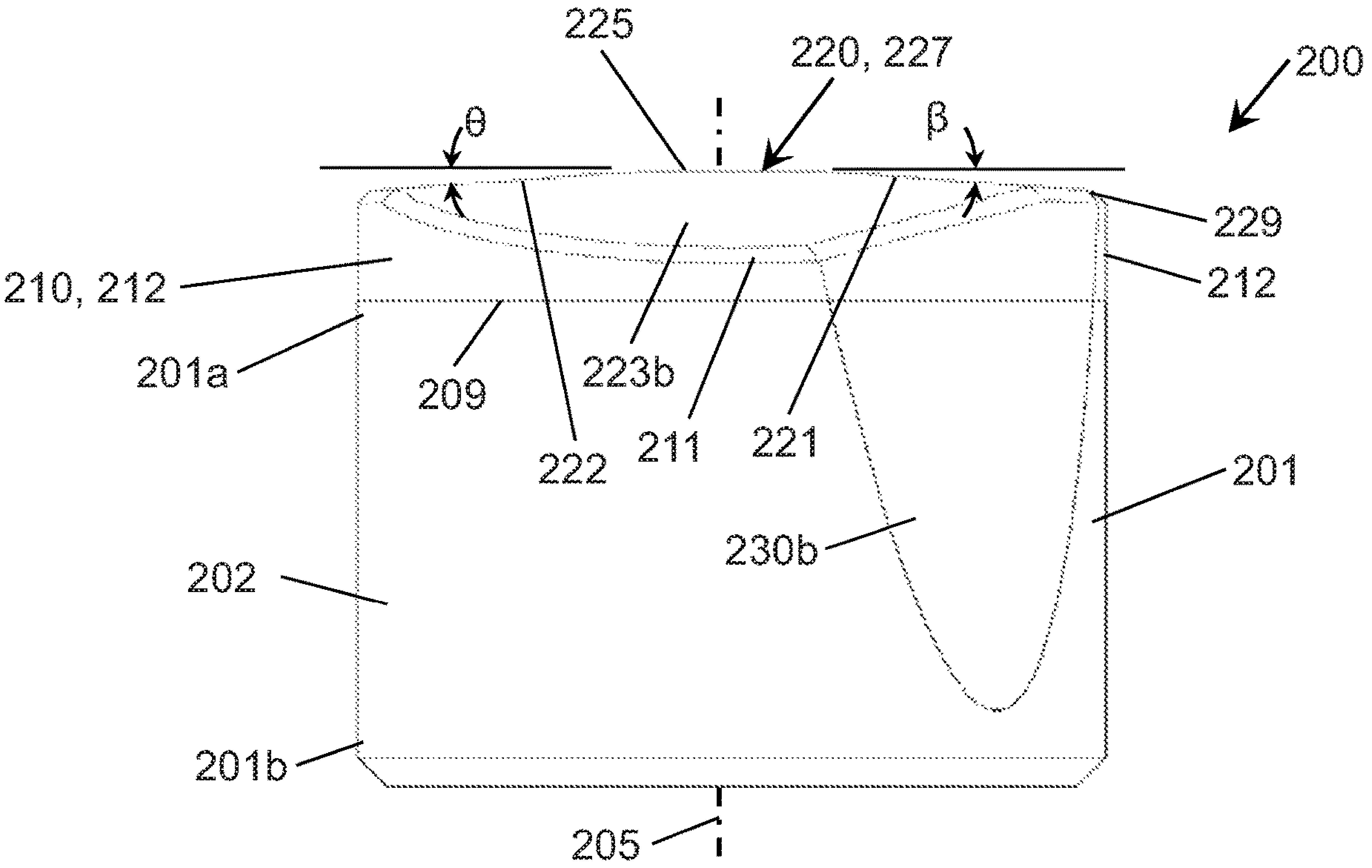

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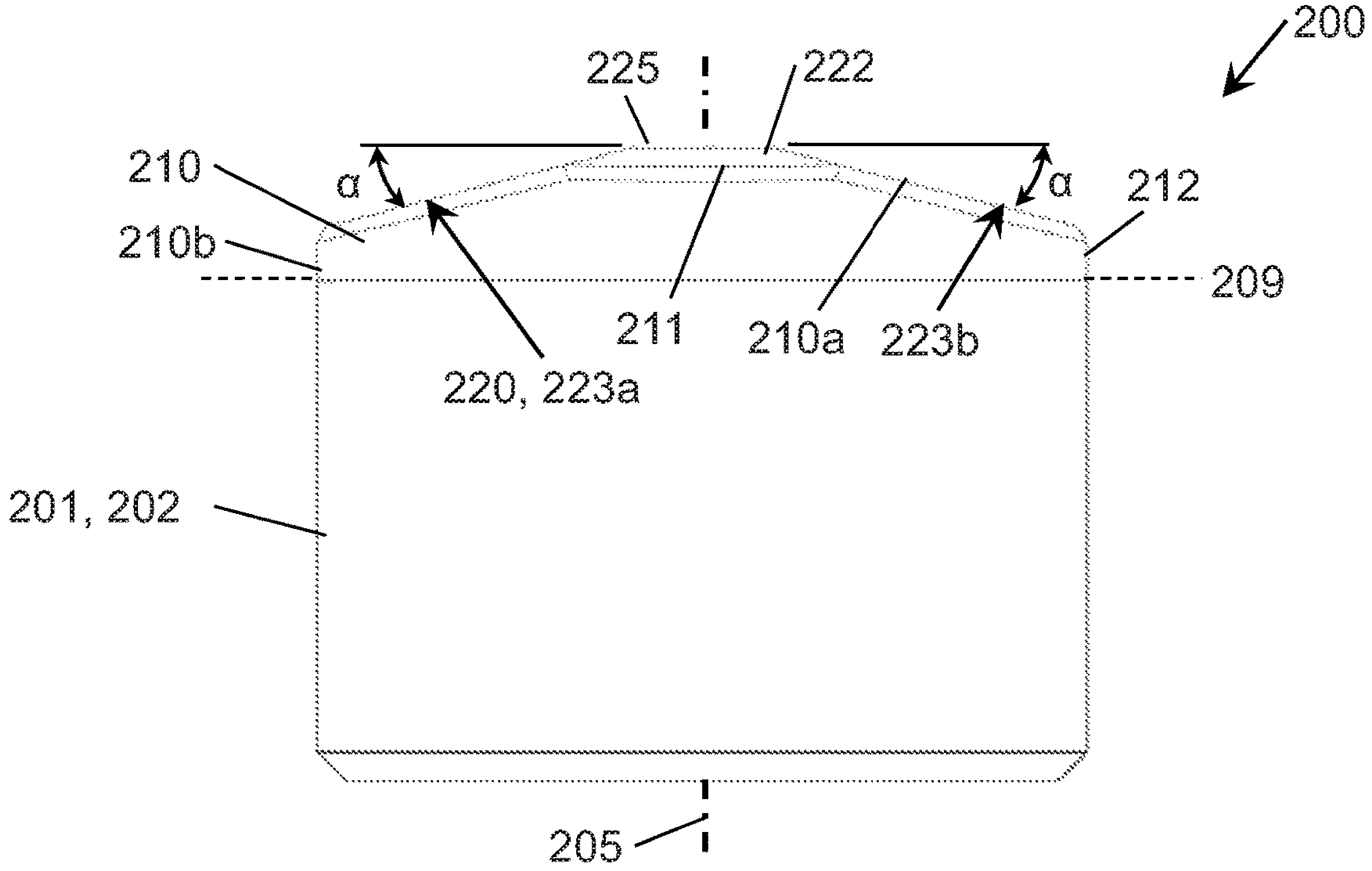

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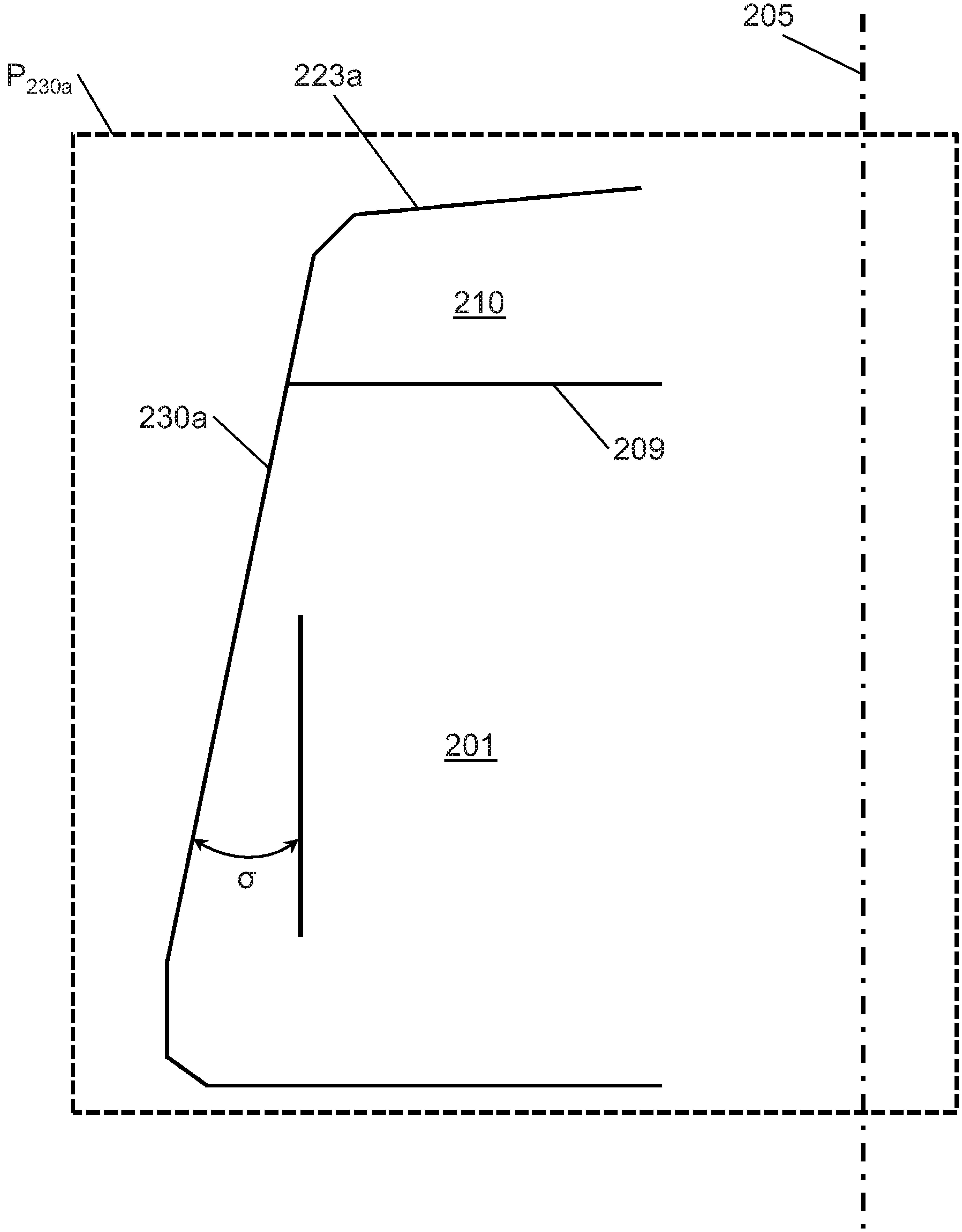

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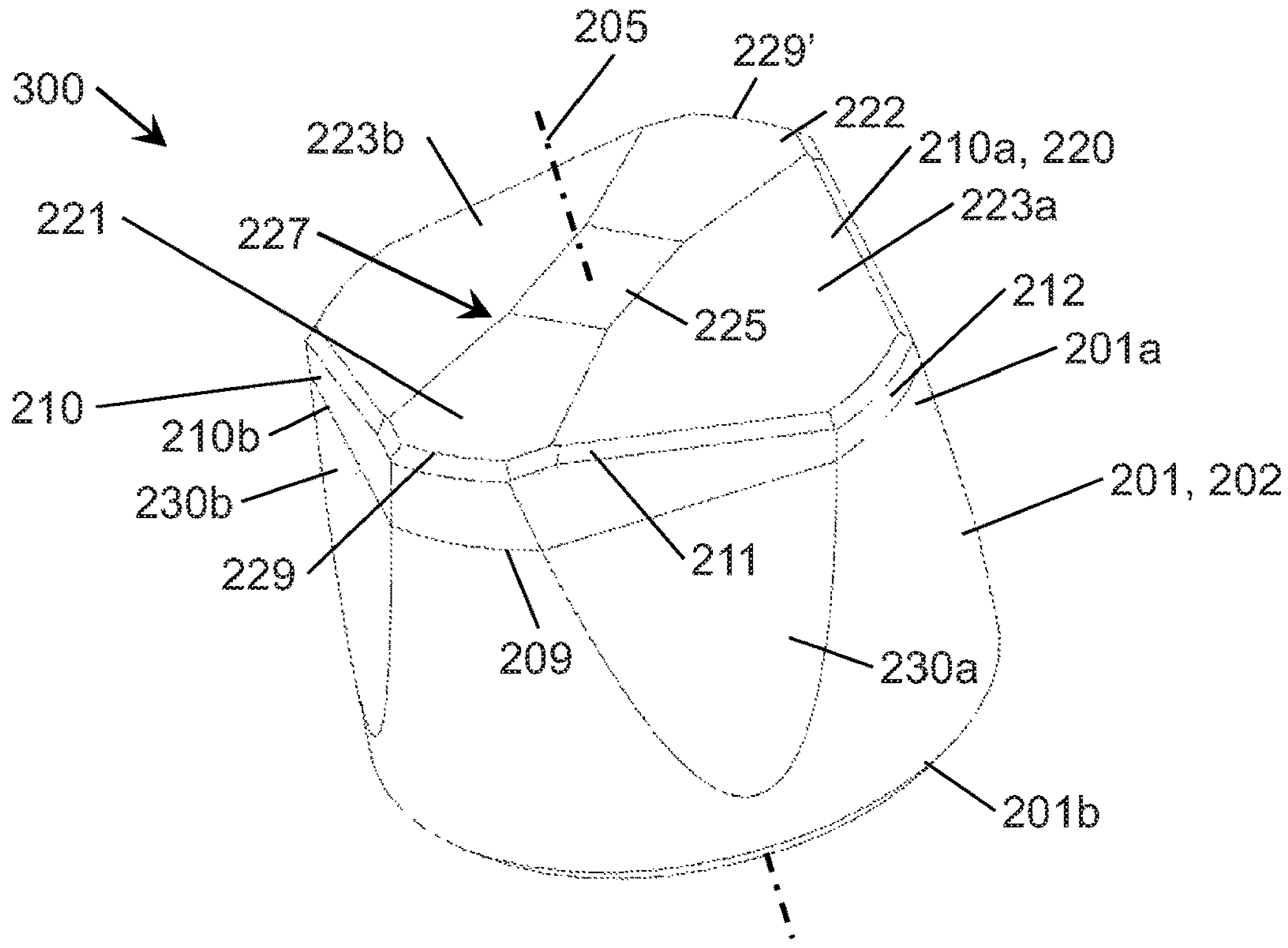

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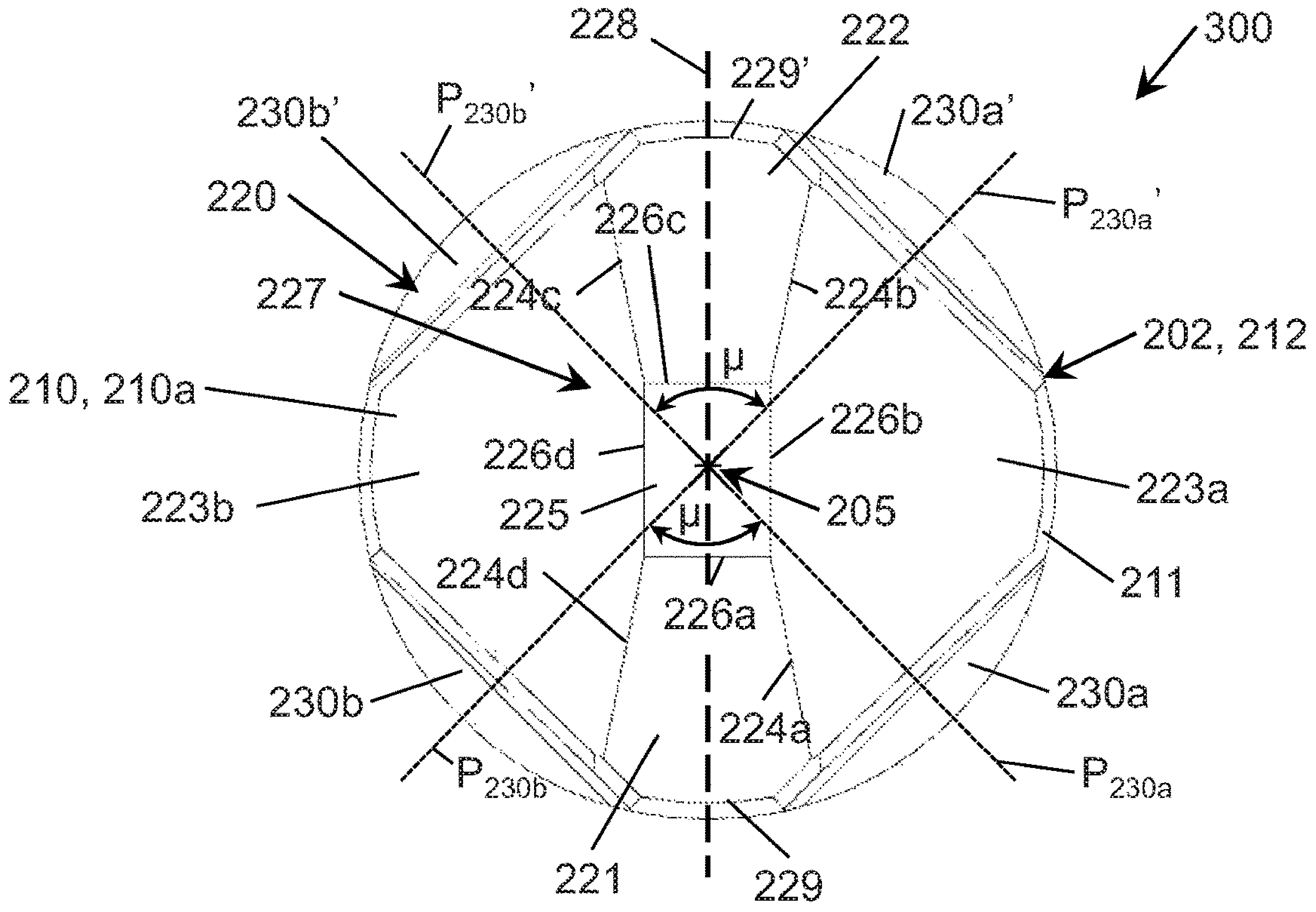

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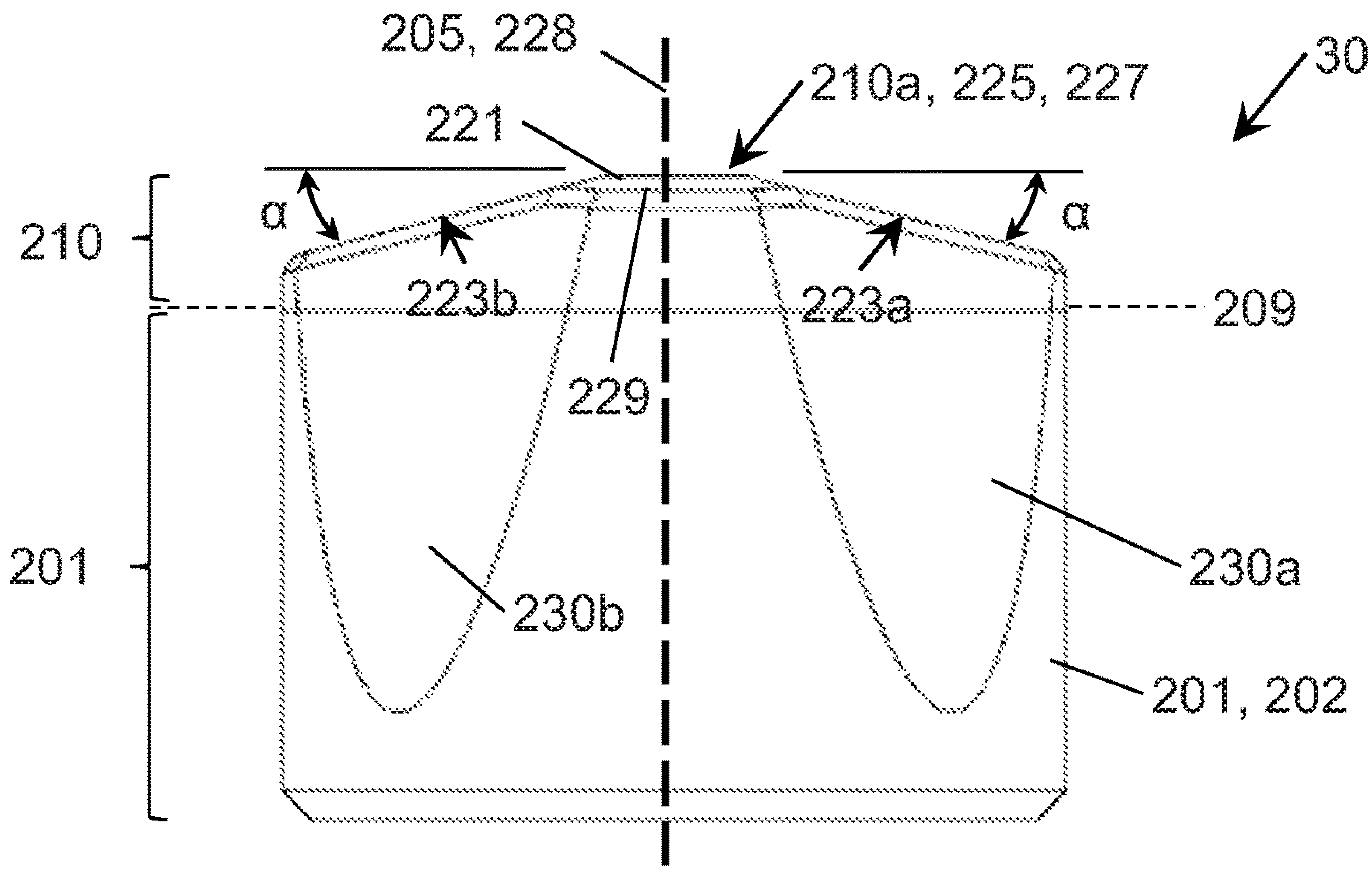

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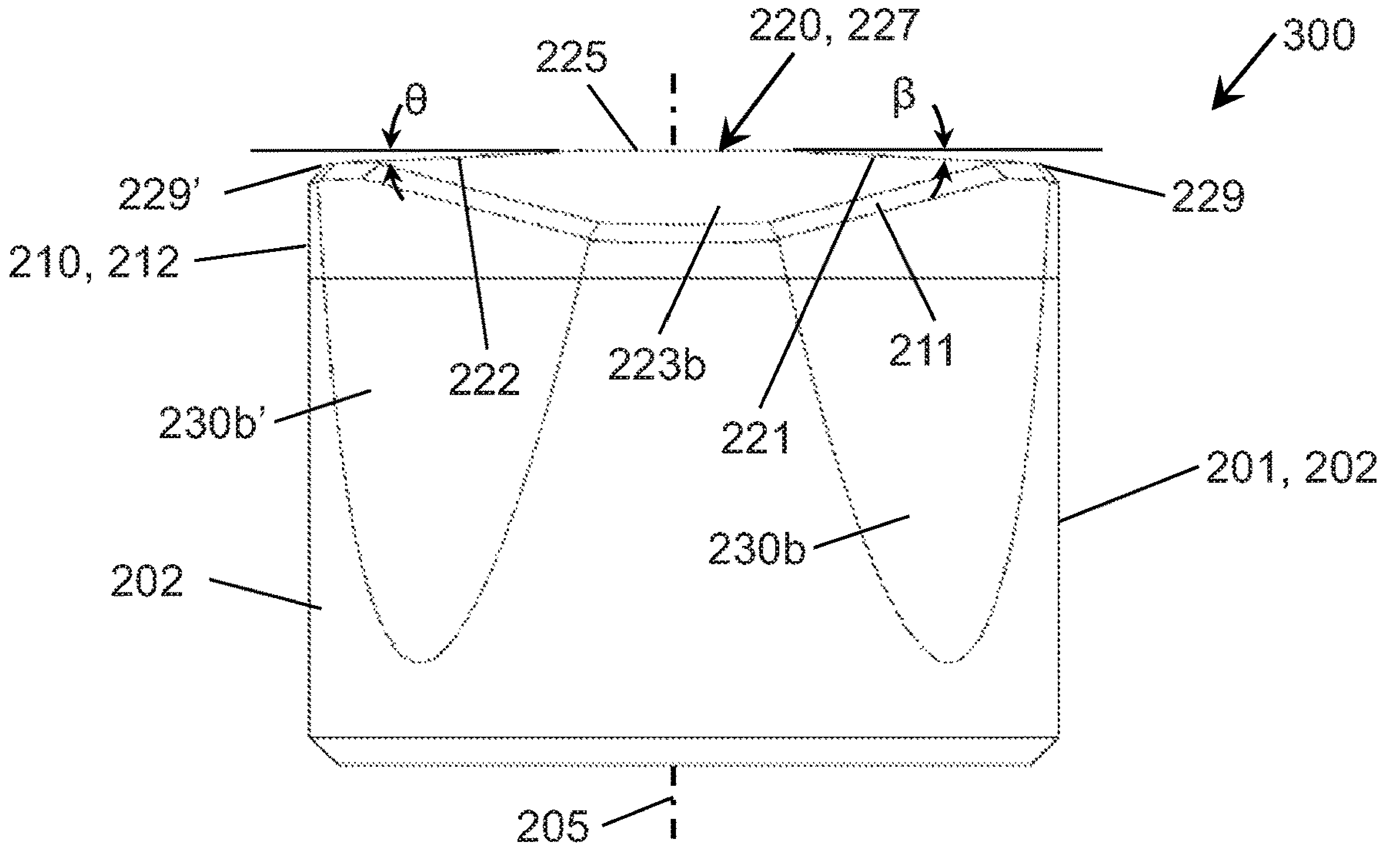

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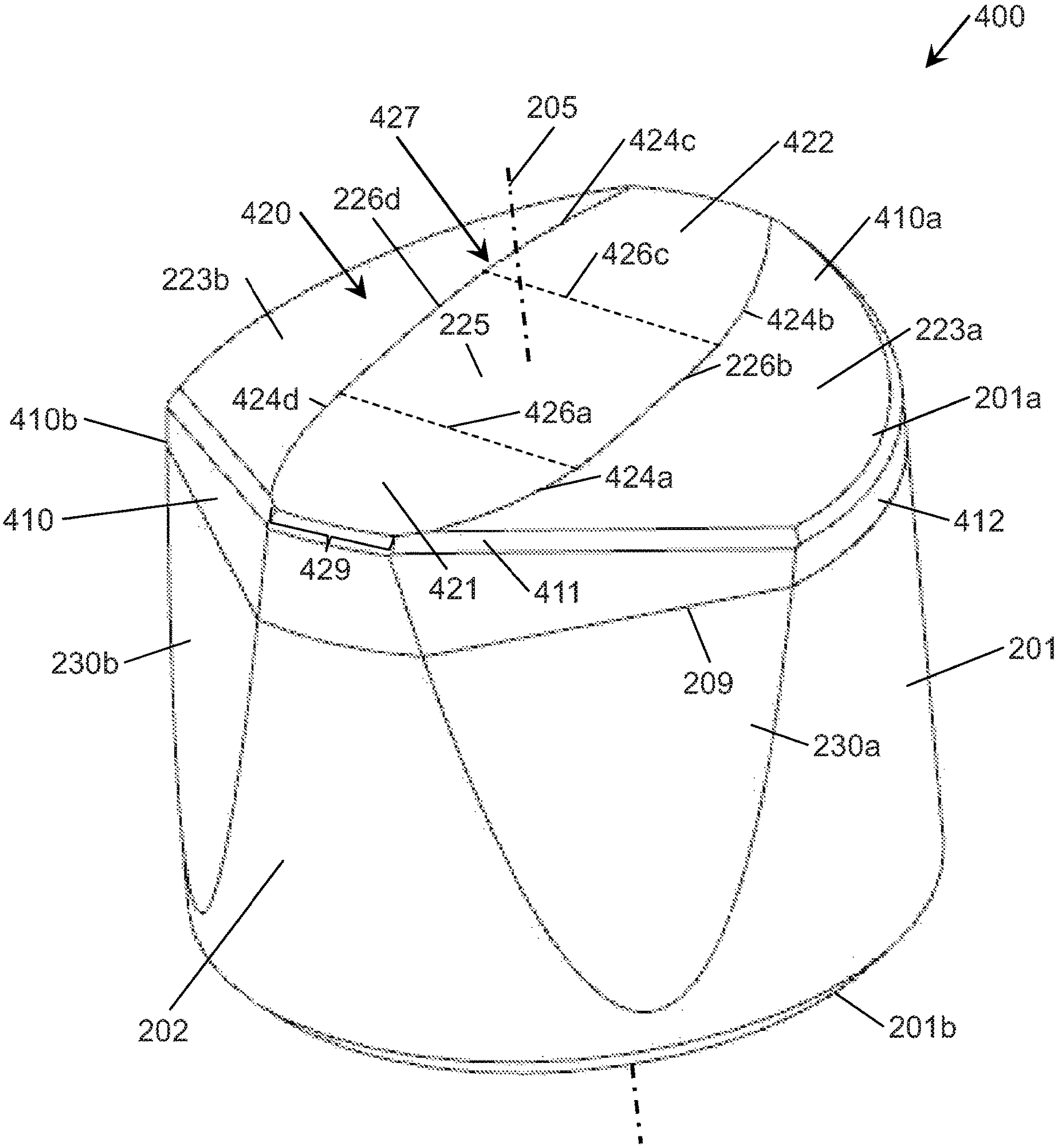
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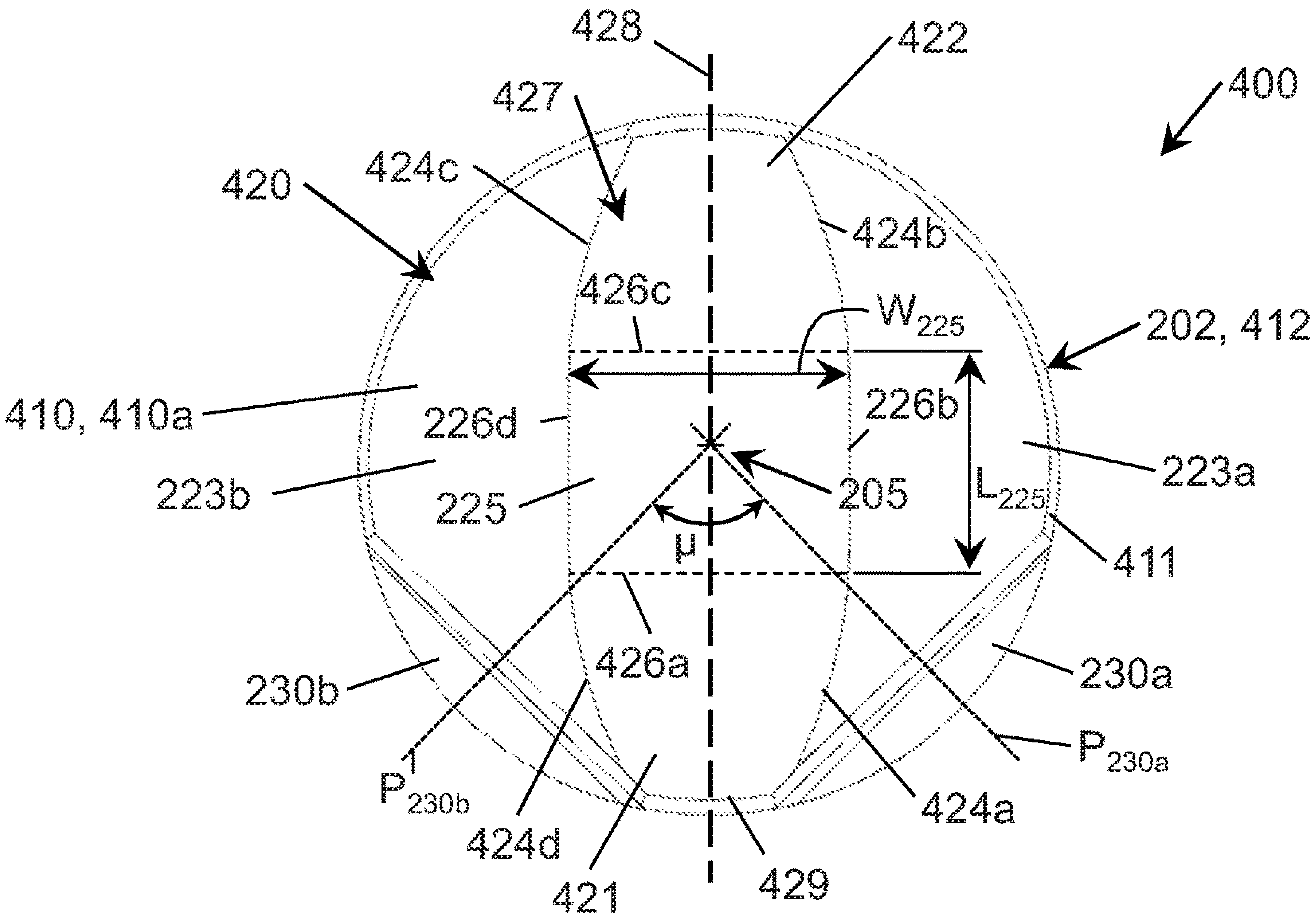

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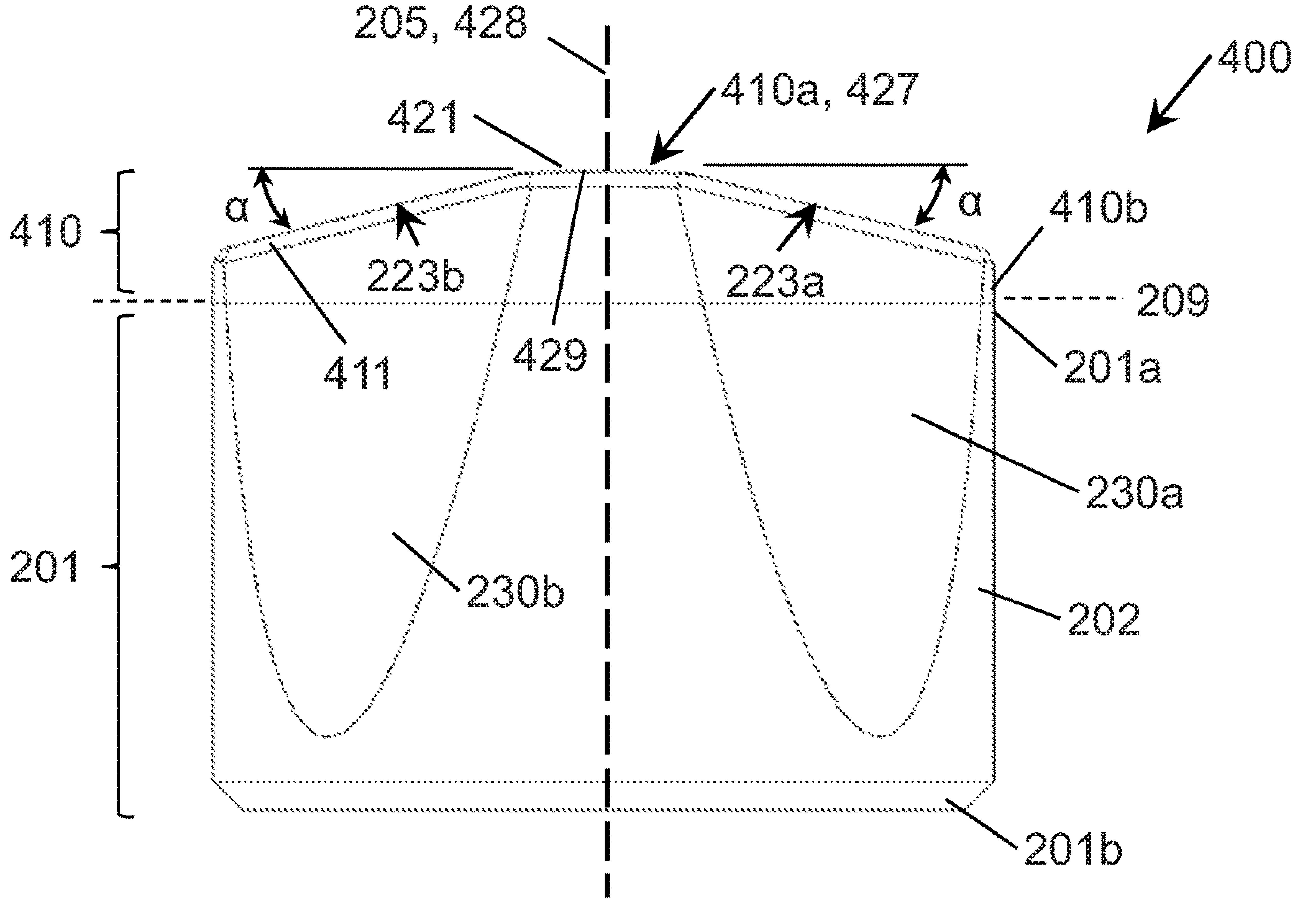

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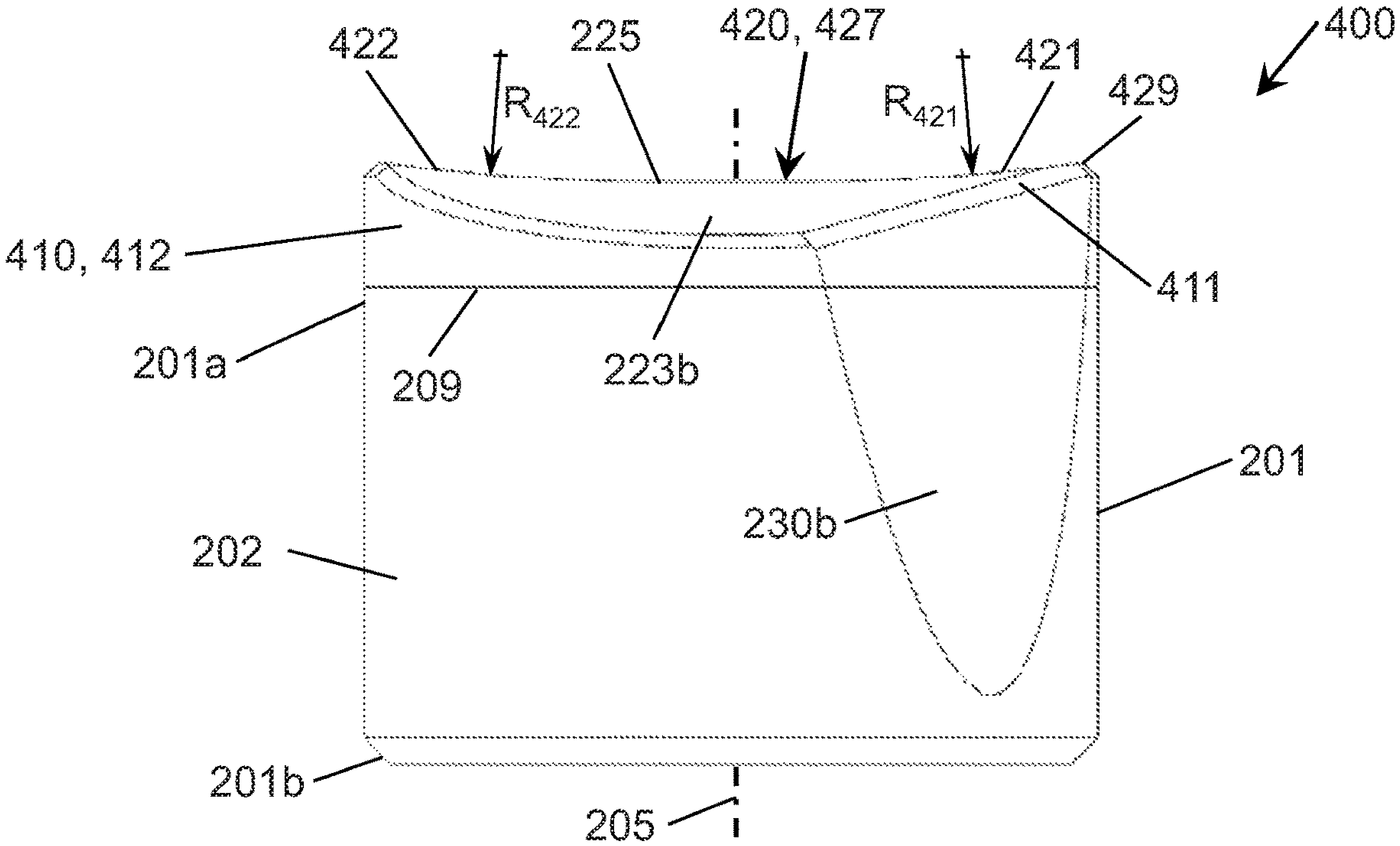

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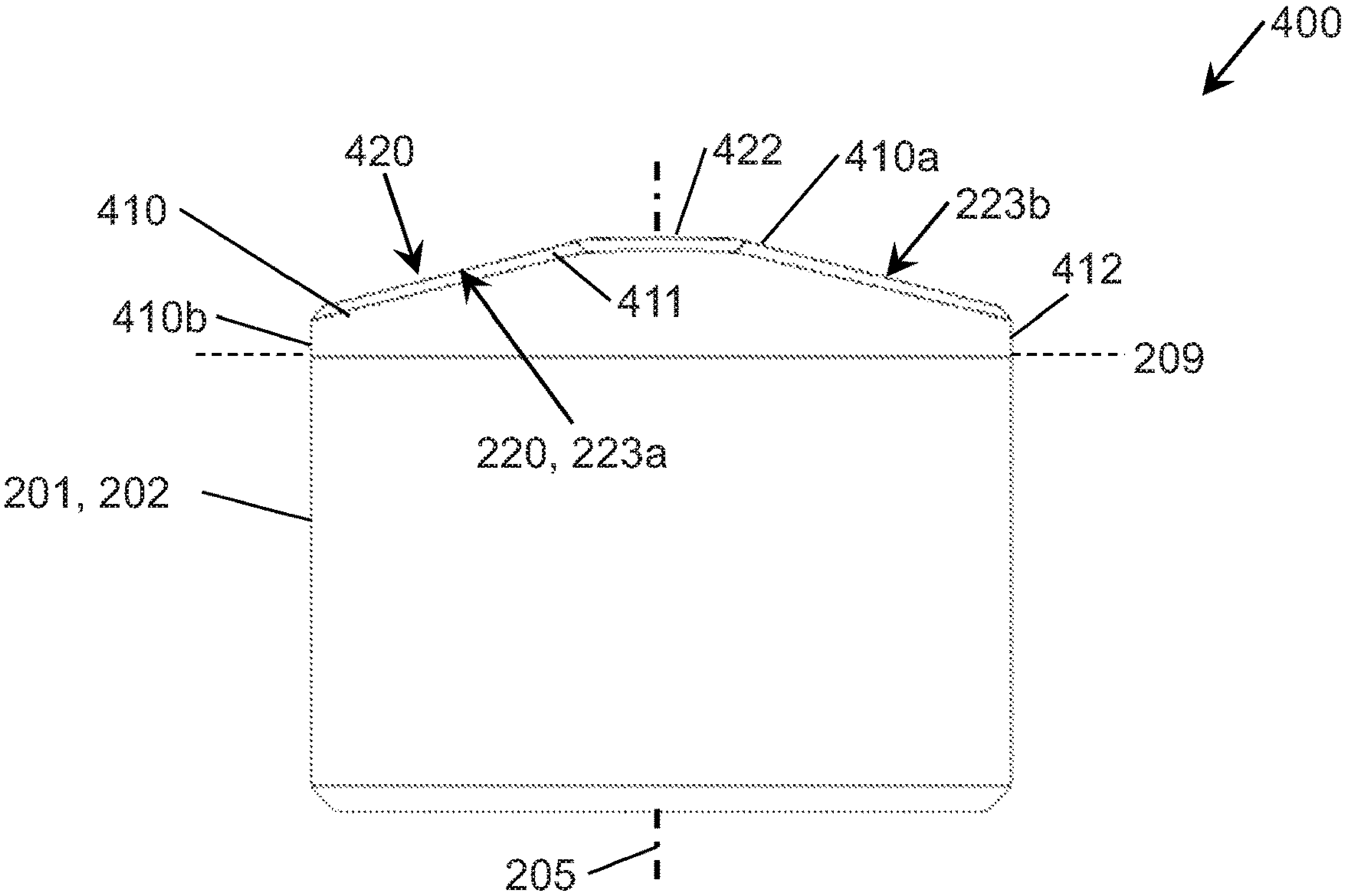

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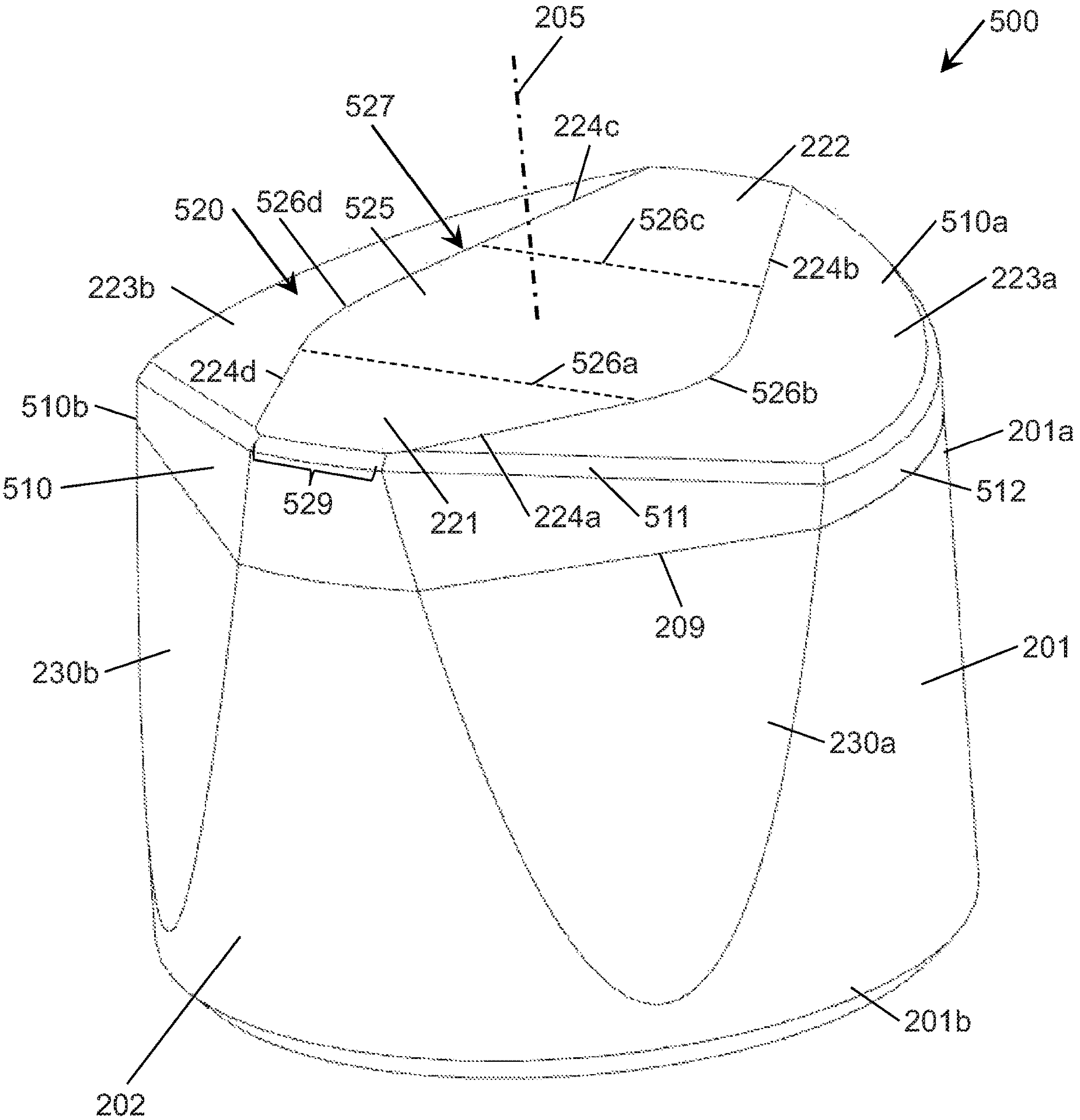
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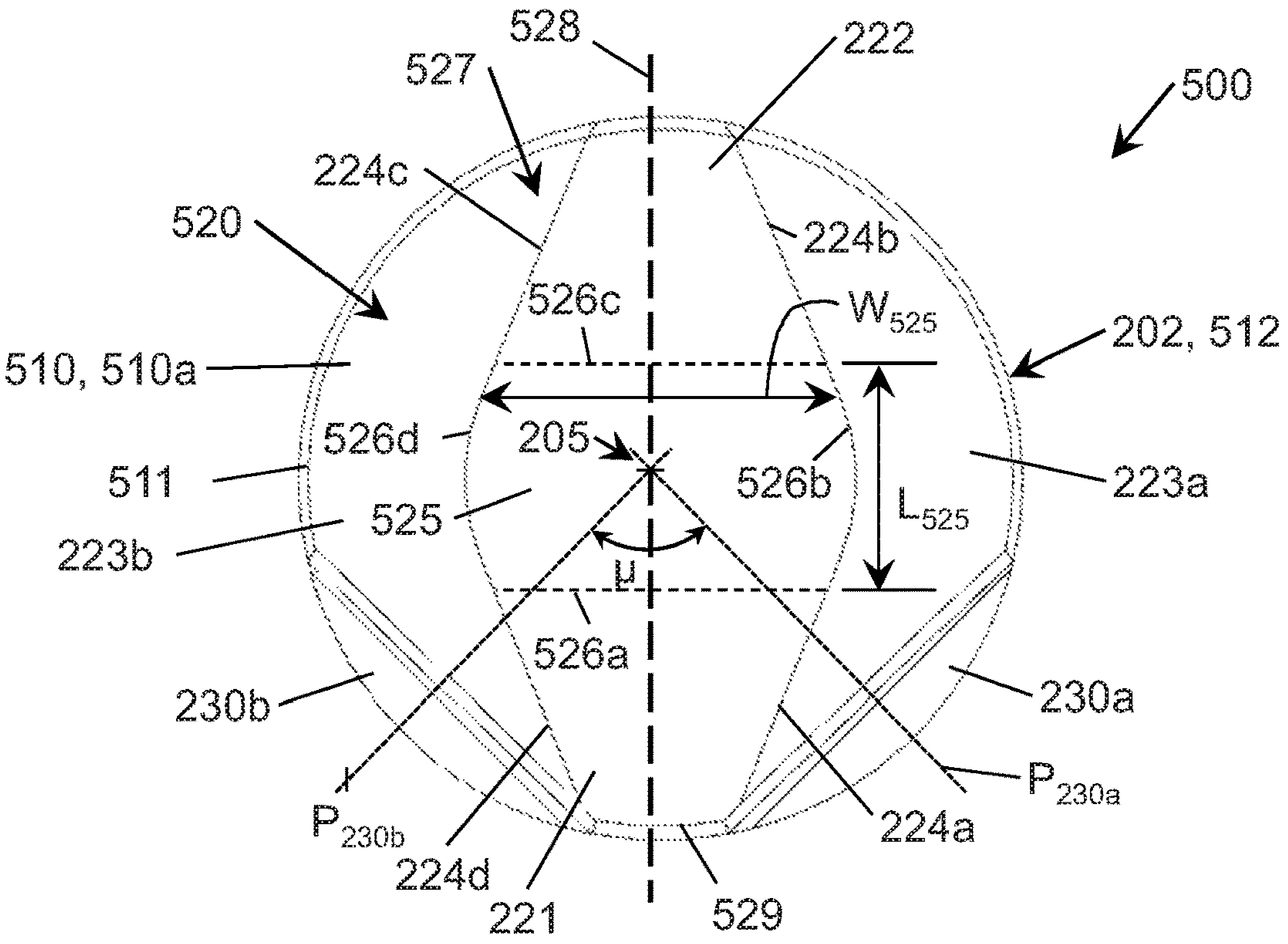

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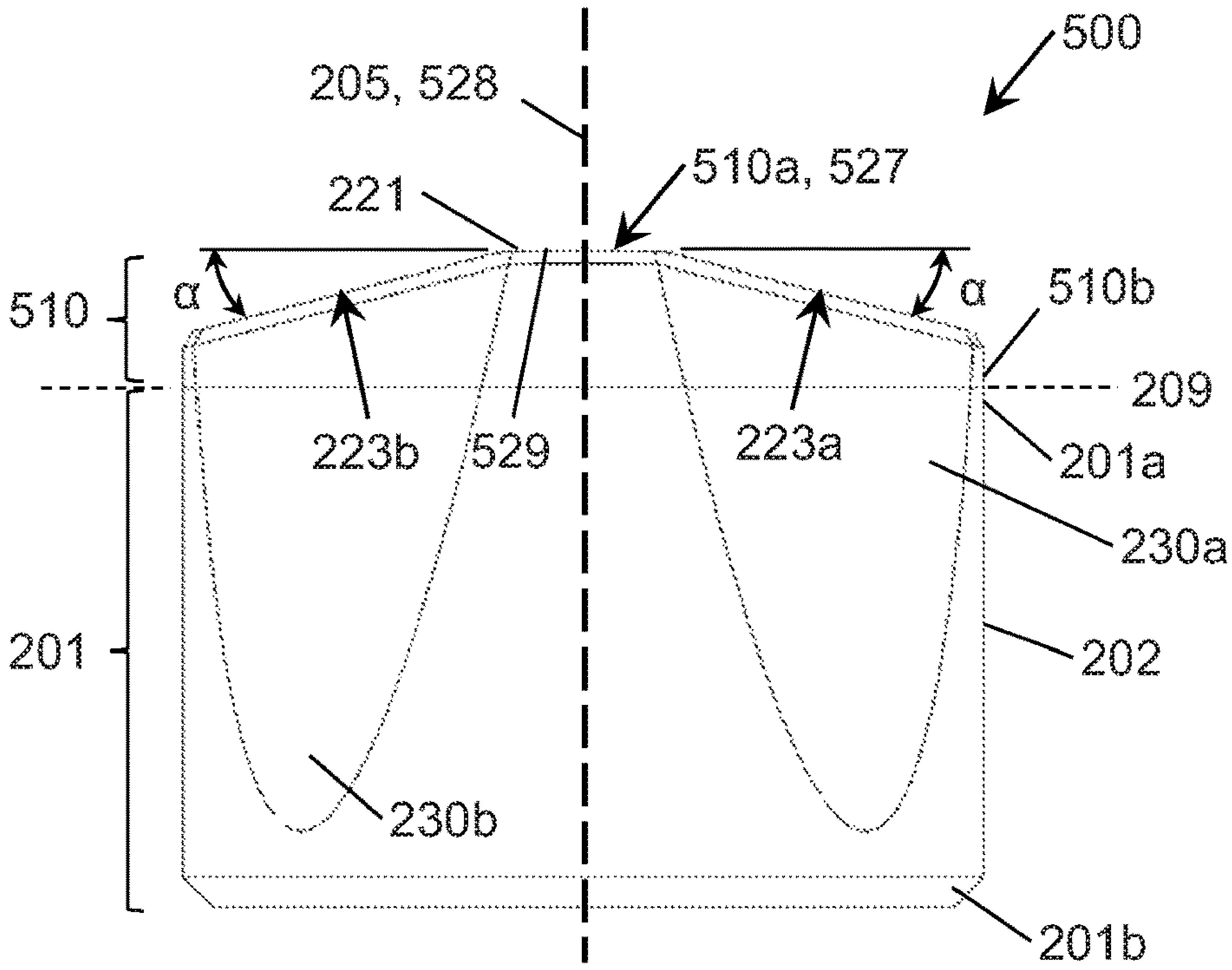

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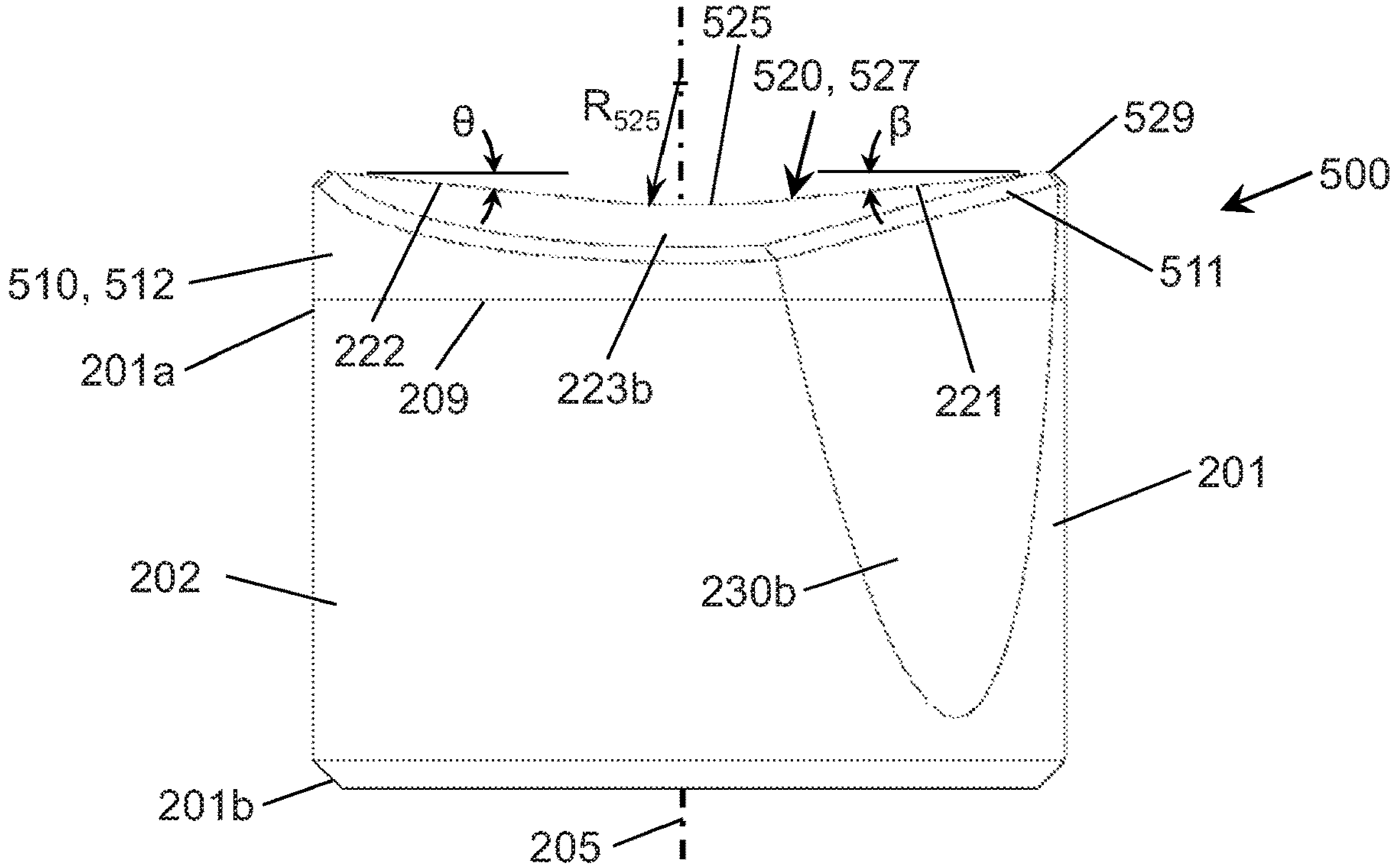

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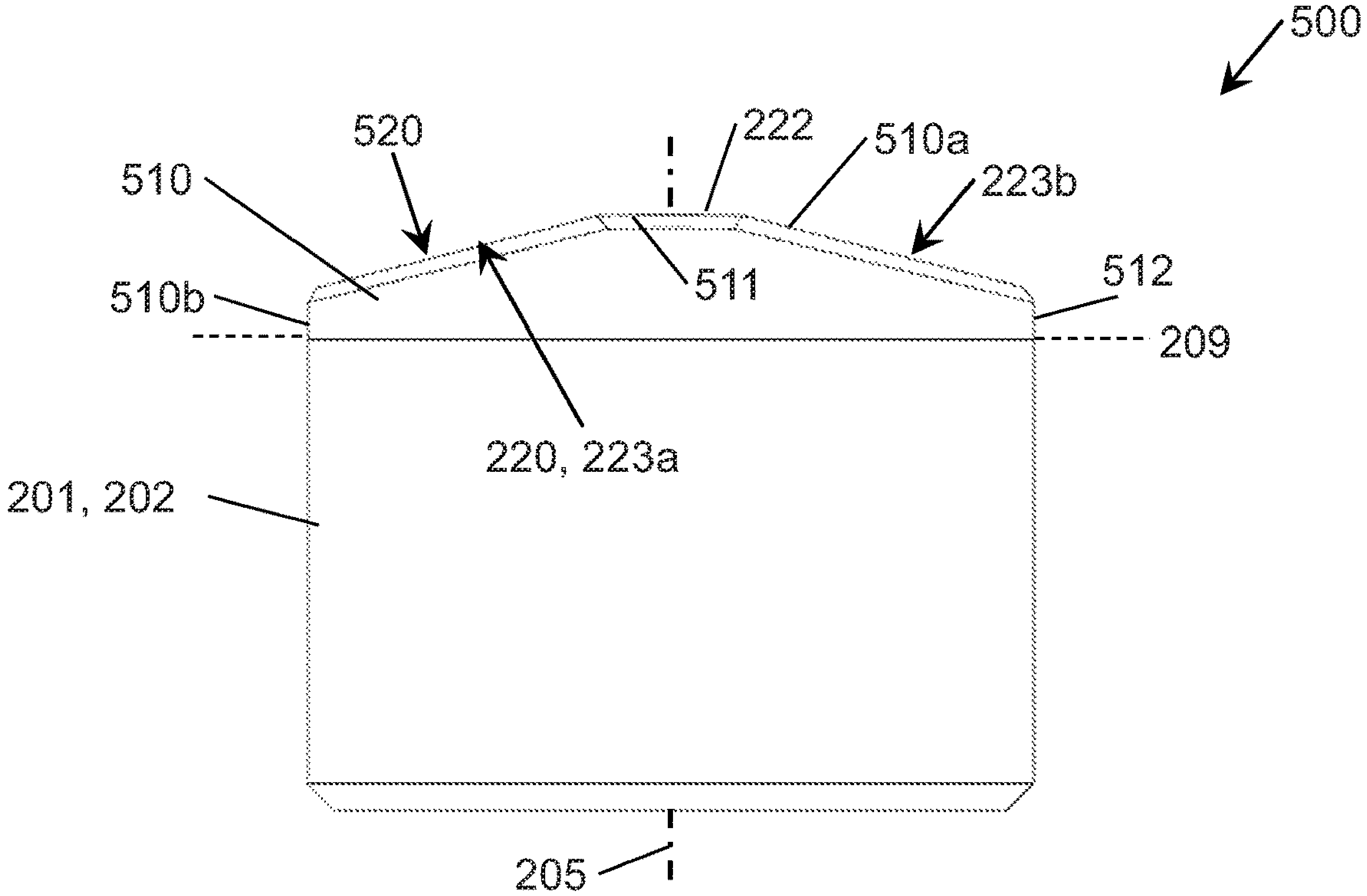

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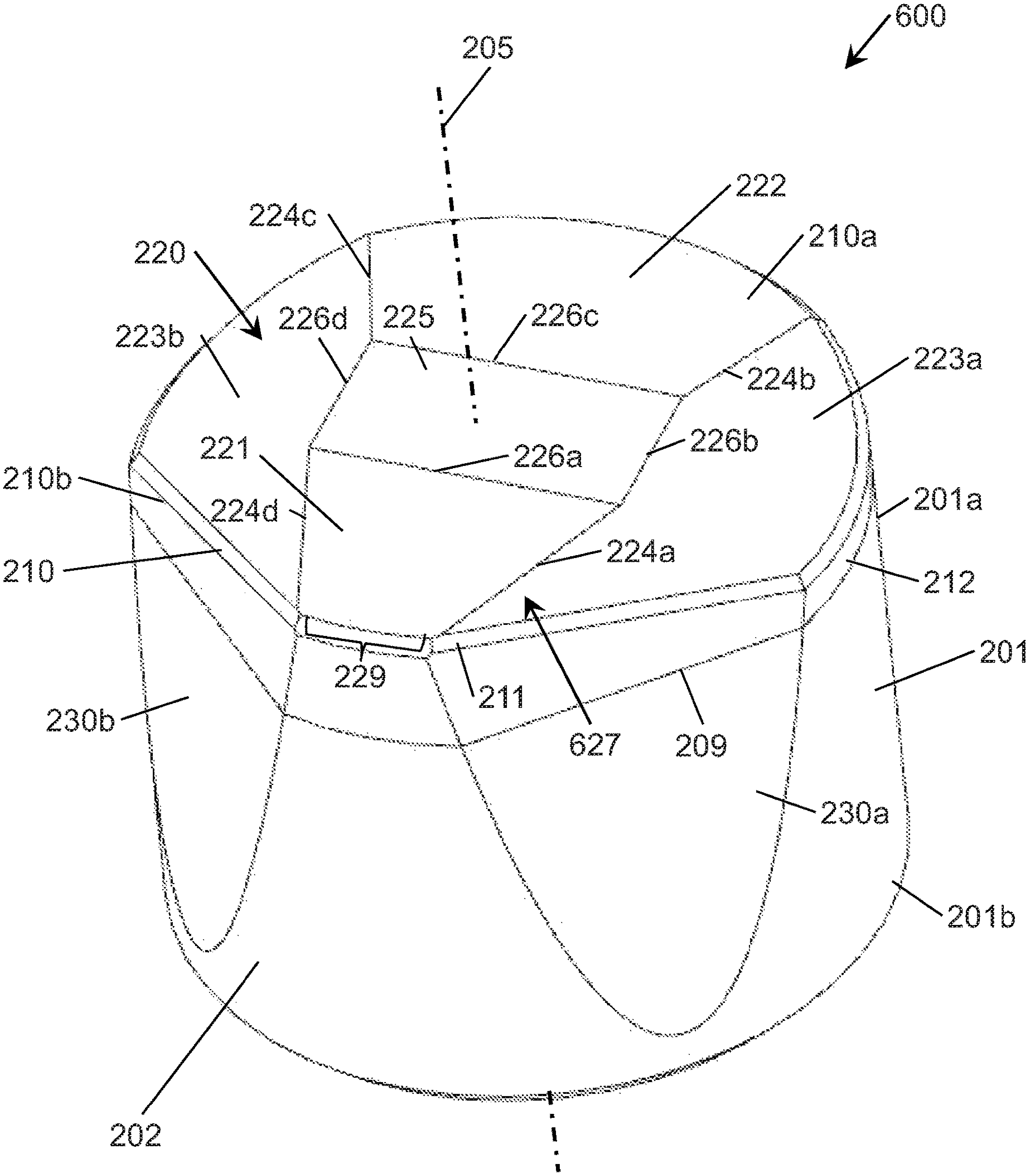
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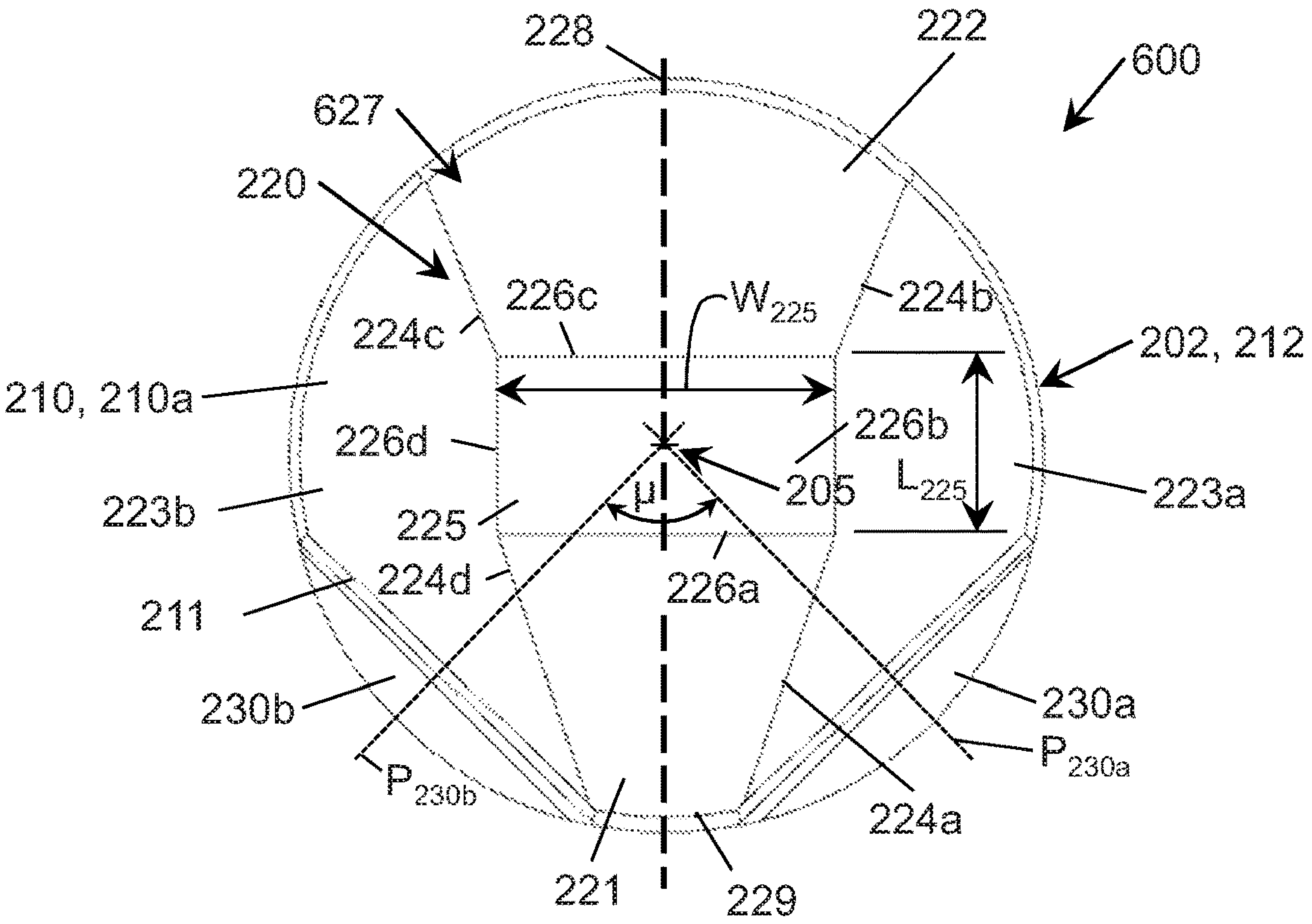
Figure 9A



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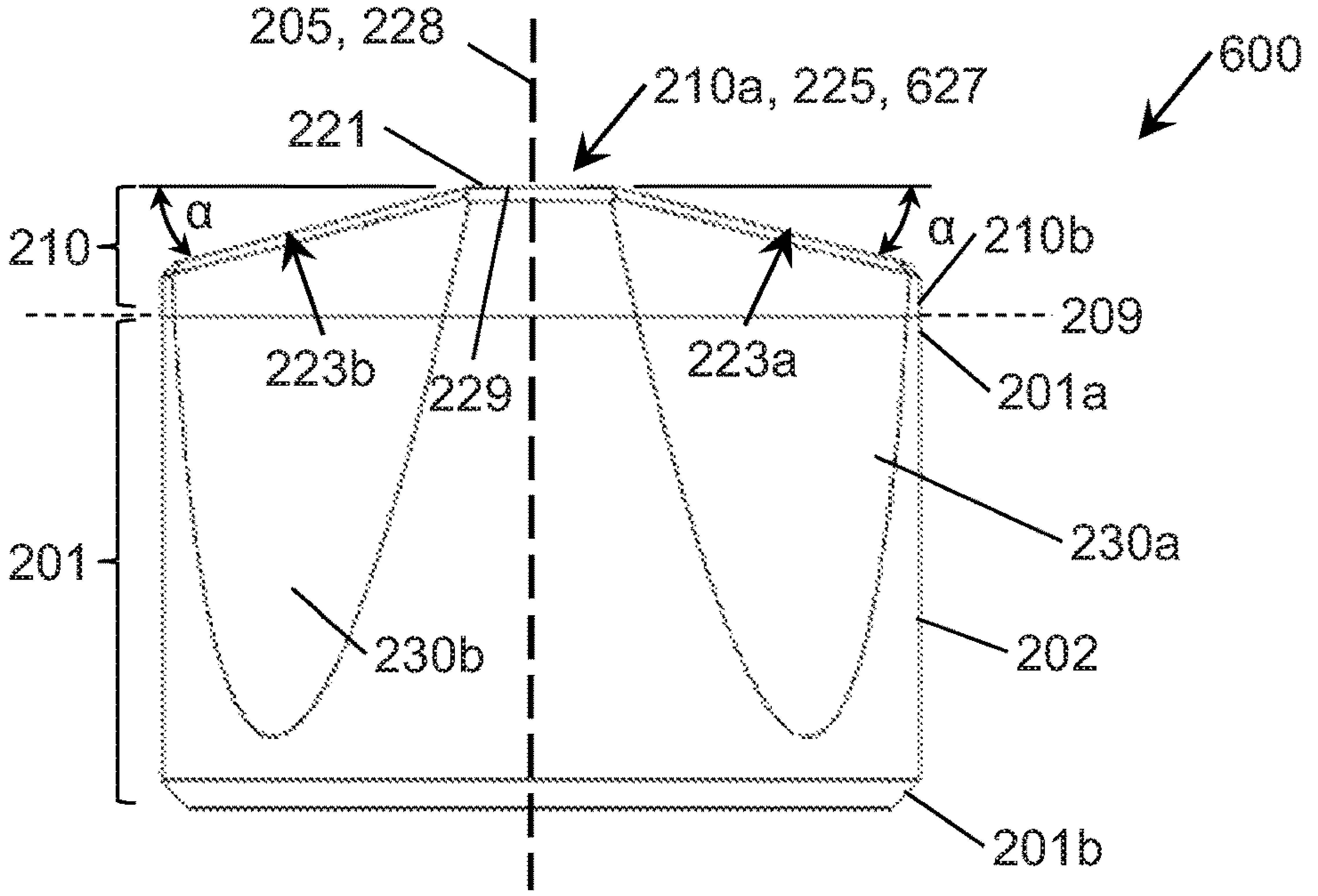

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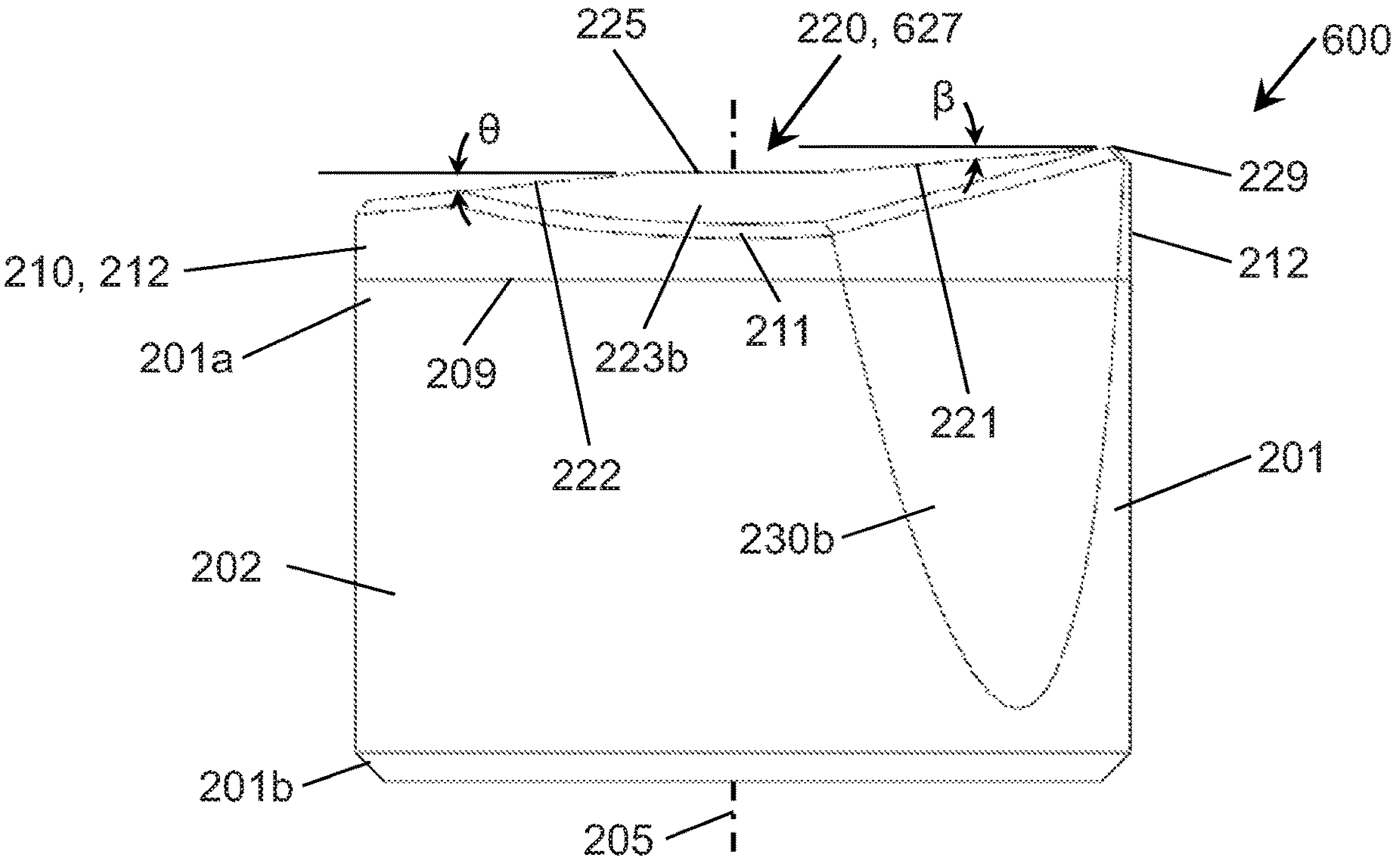

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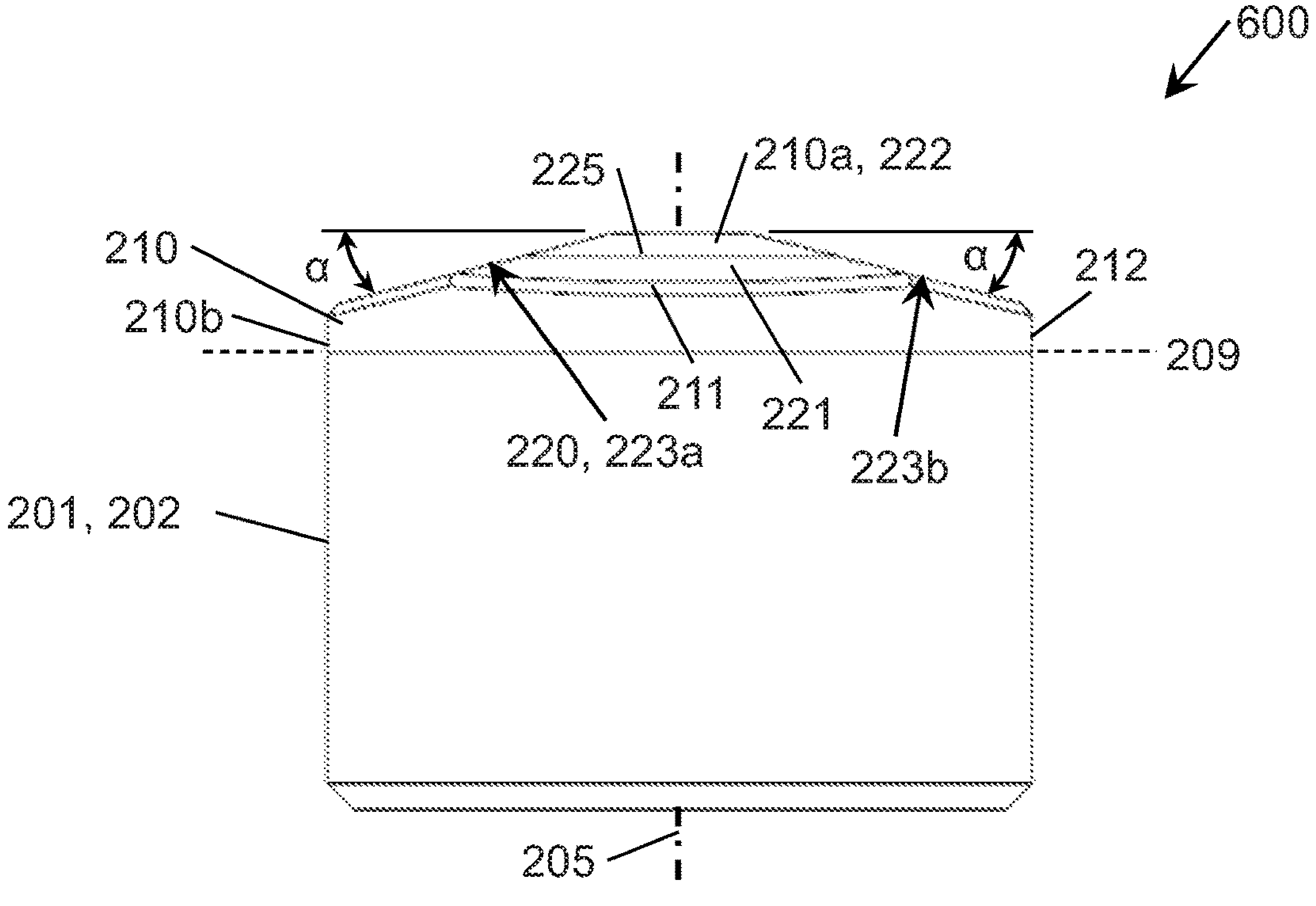

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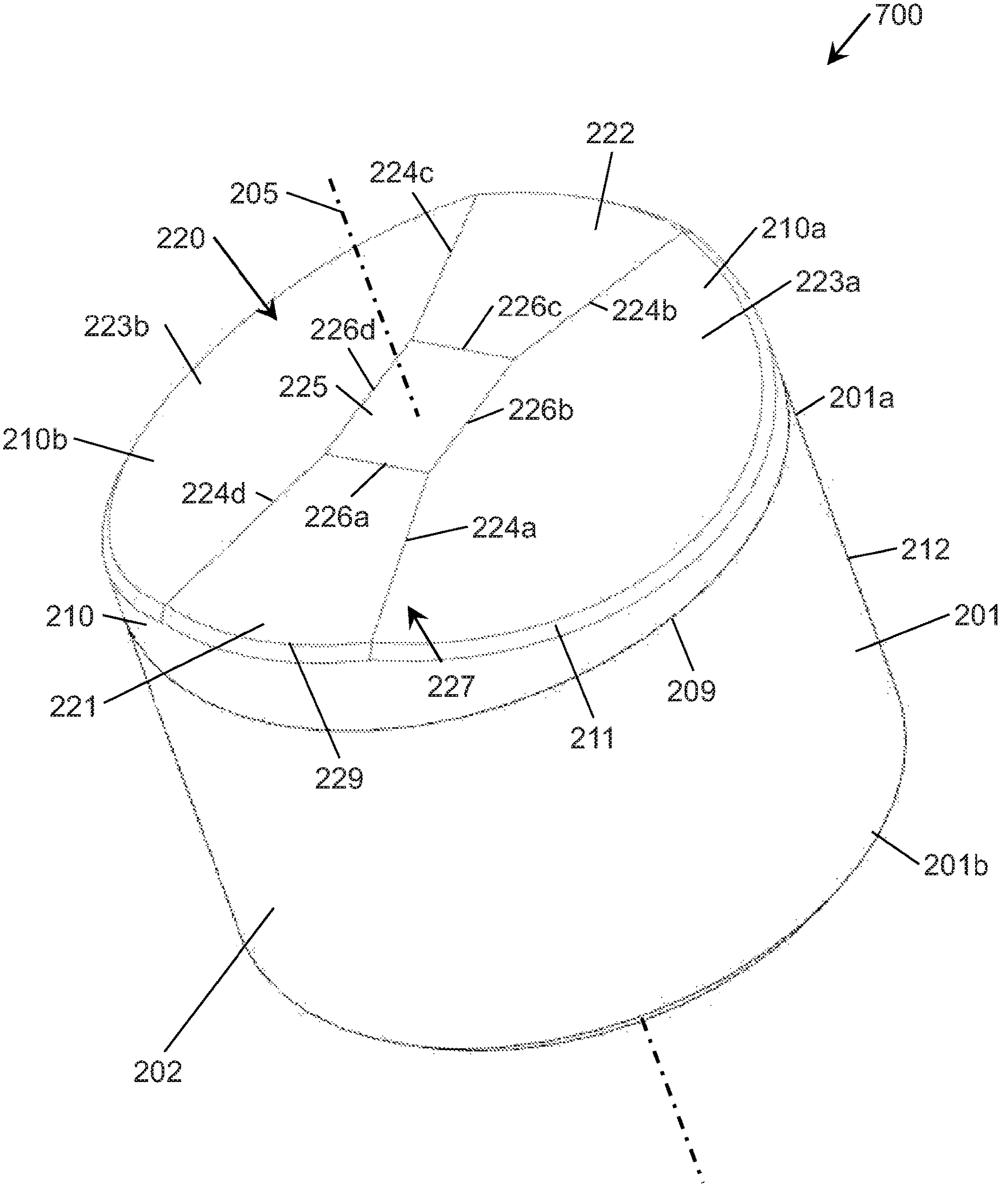
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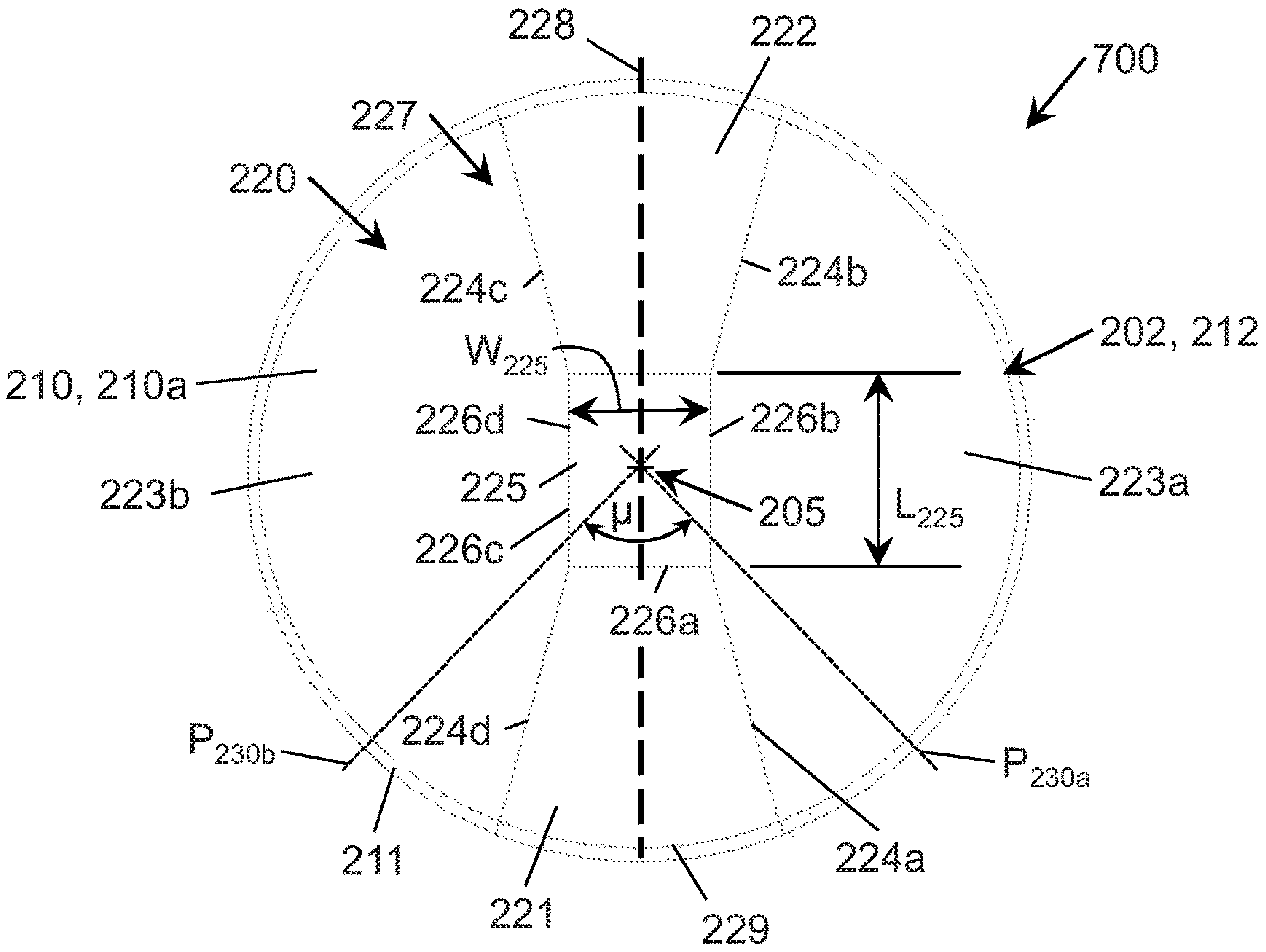
Figure 10A



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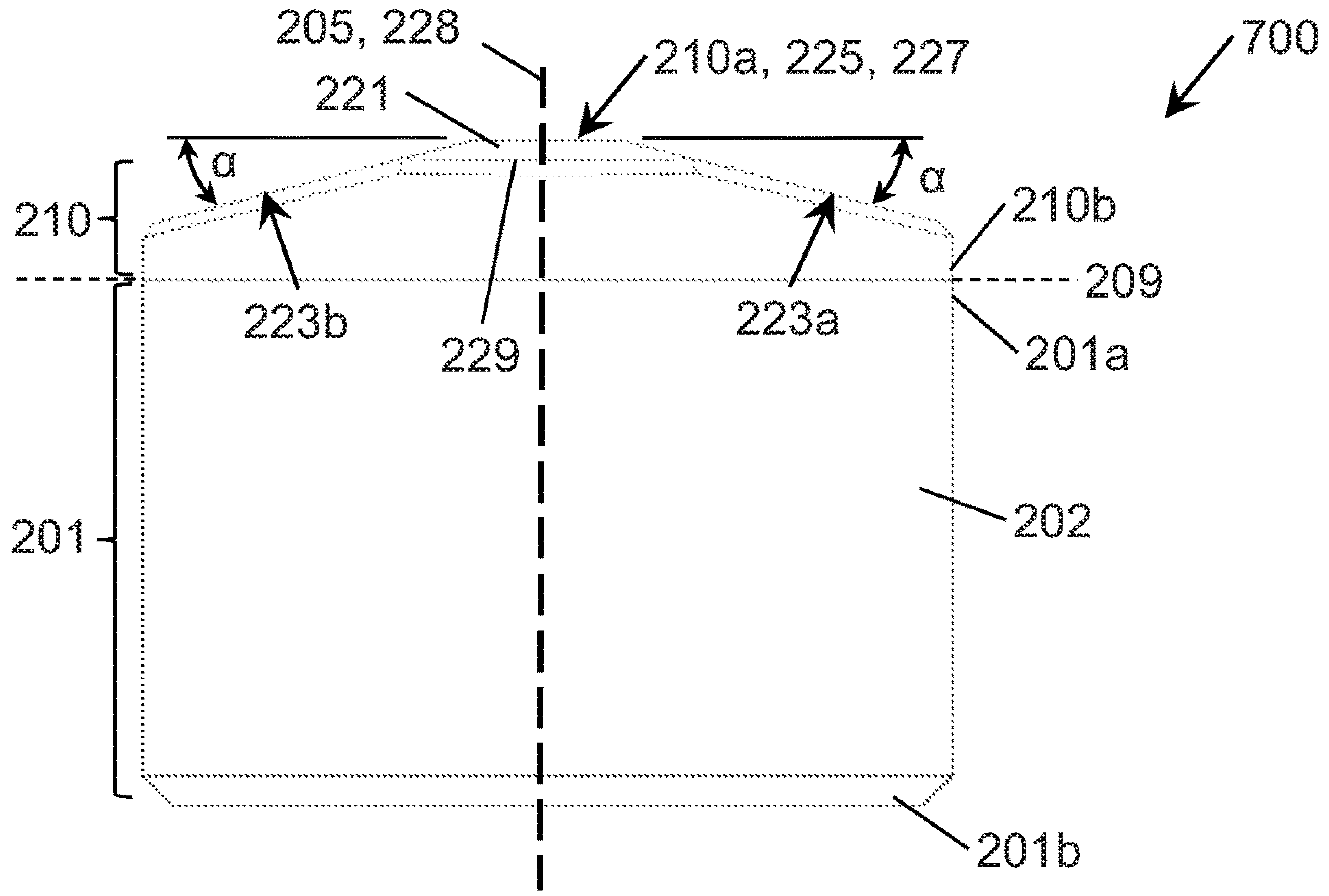

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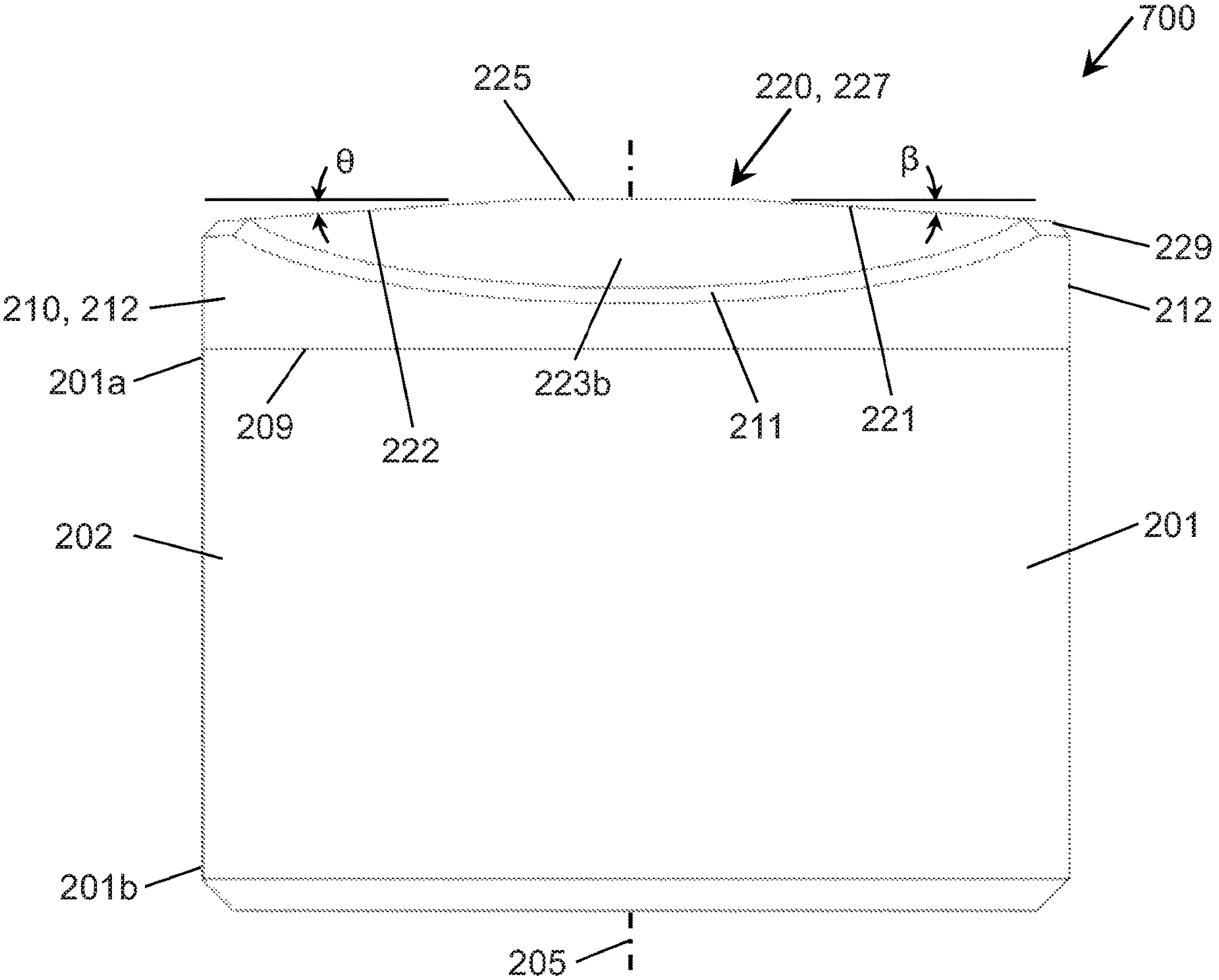
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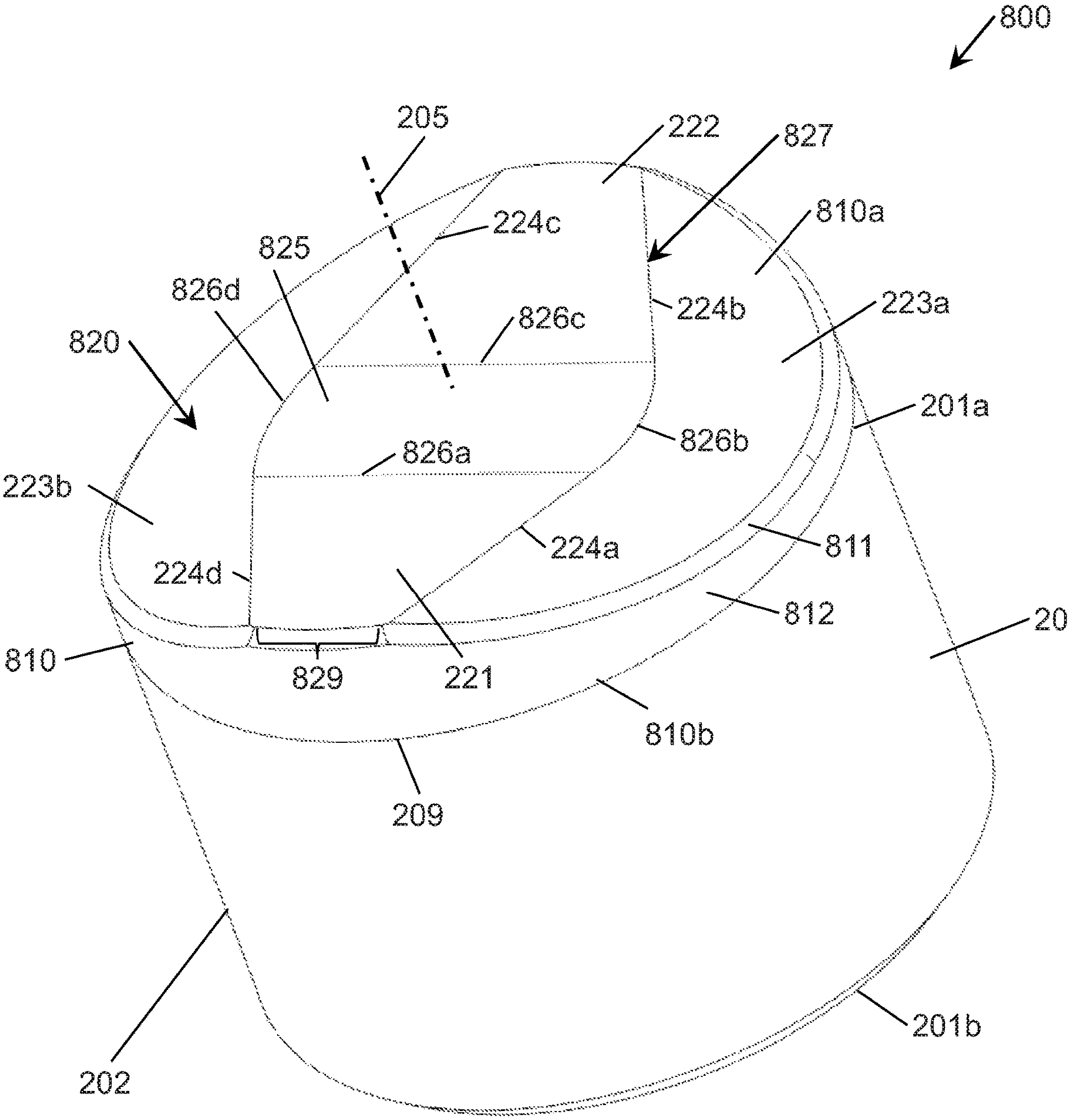
Figure 10D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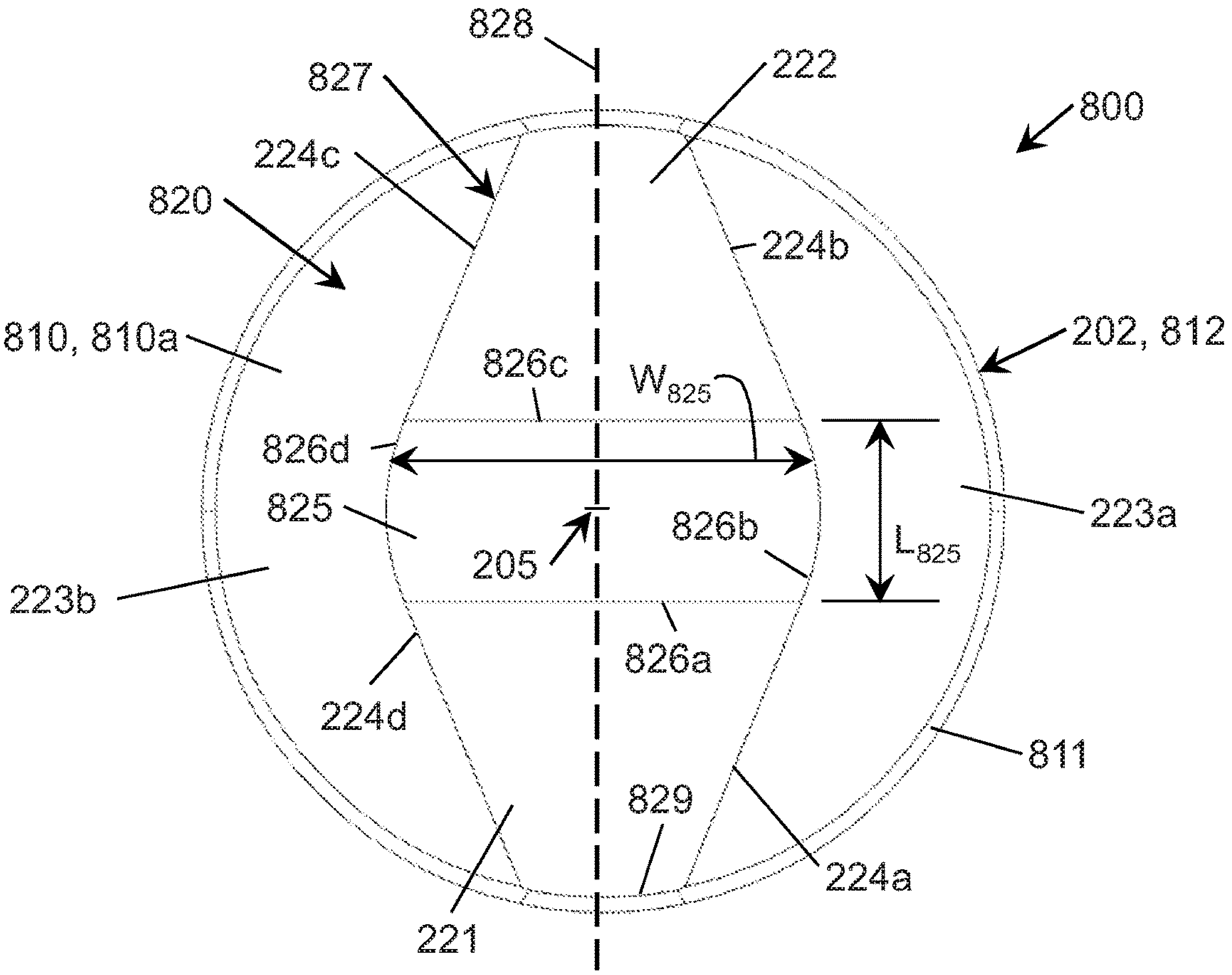

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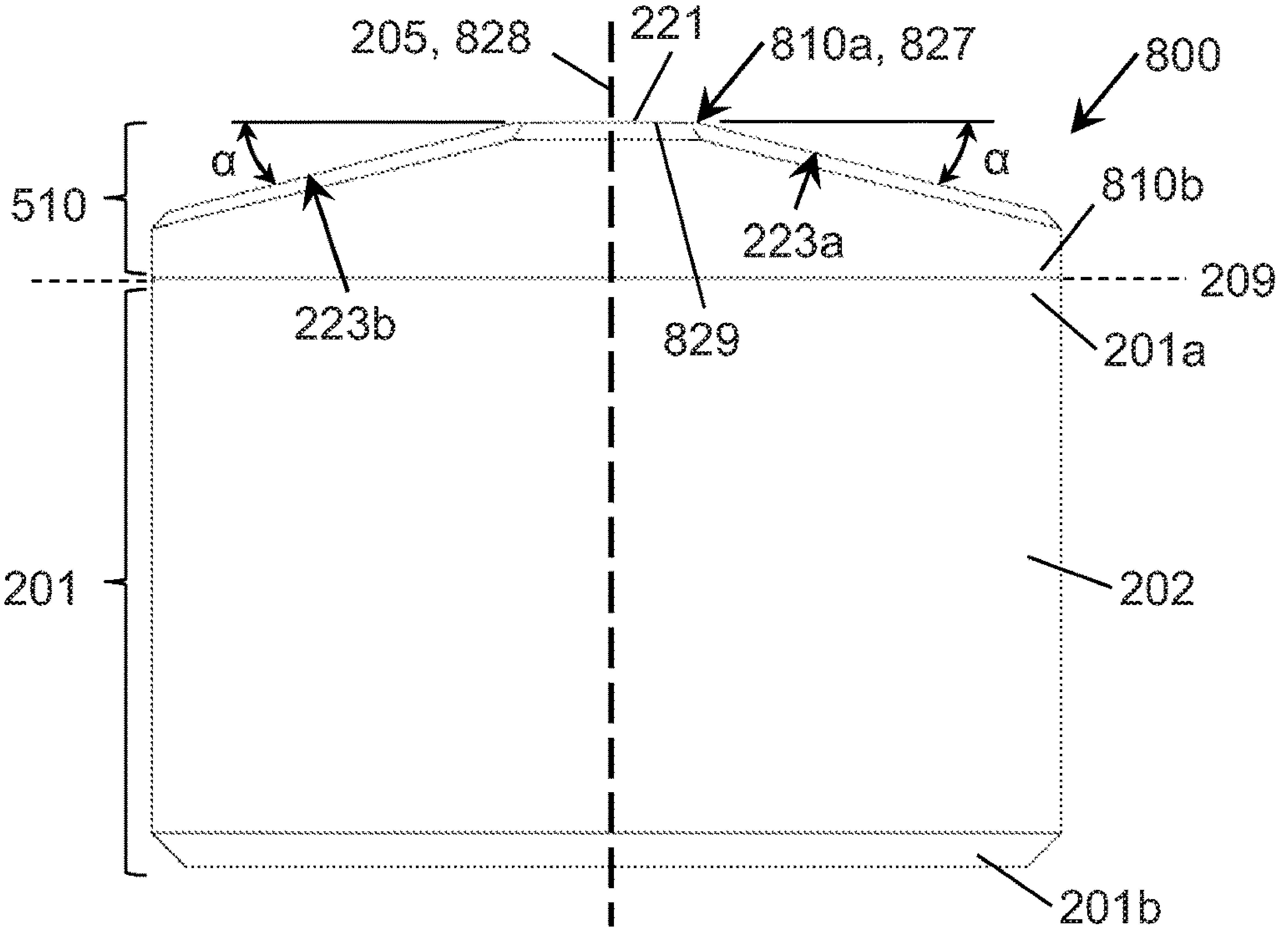

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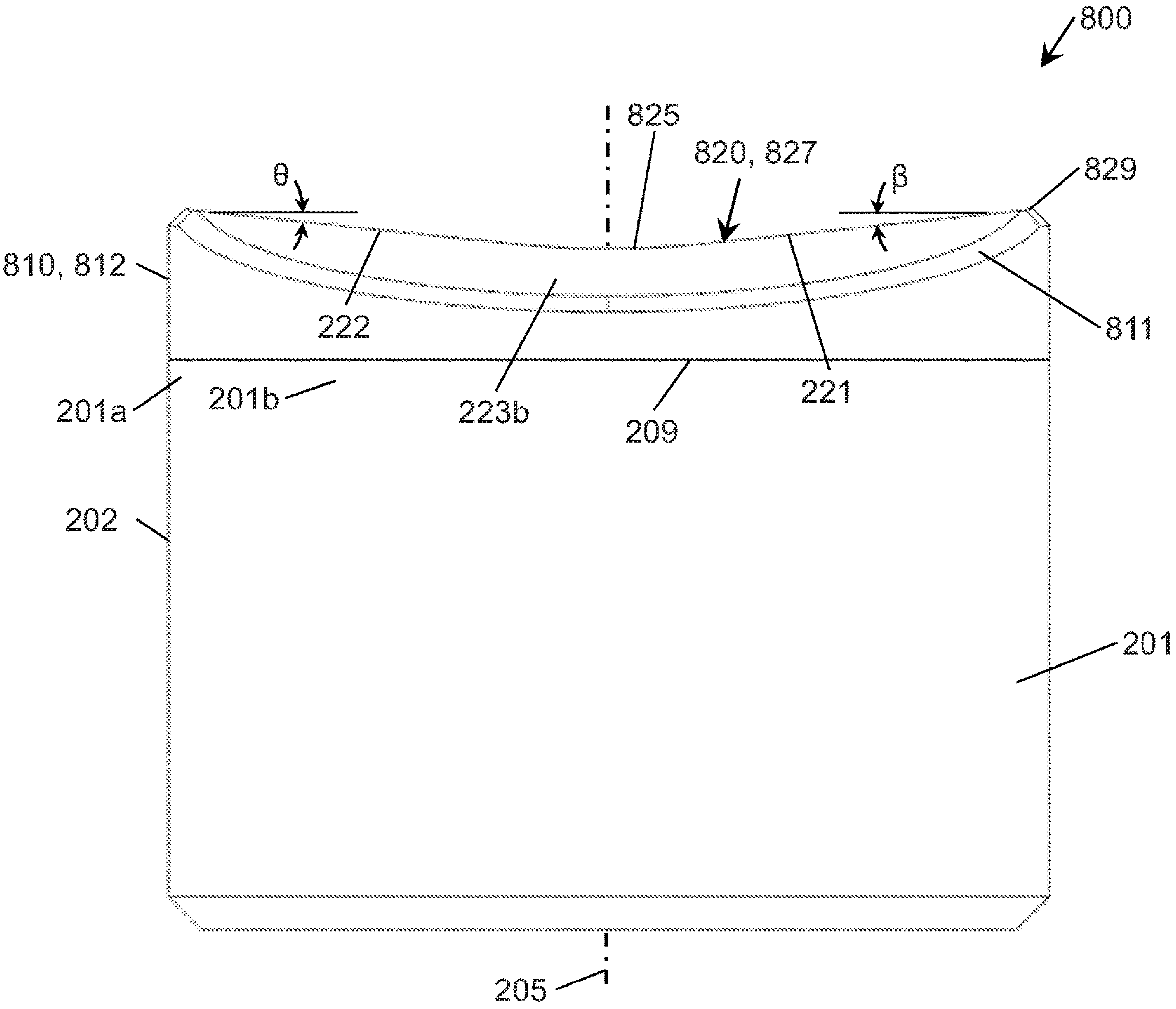
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Figure 11D

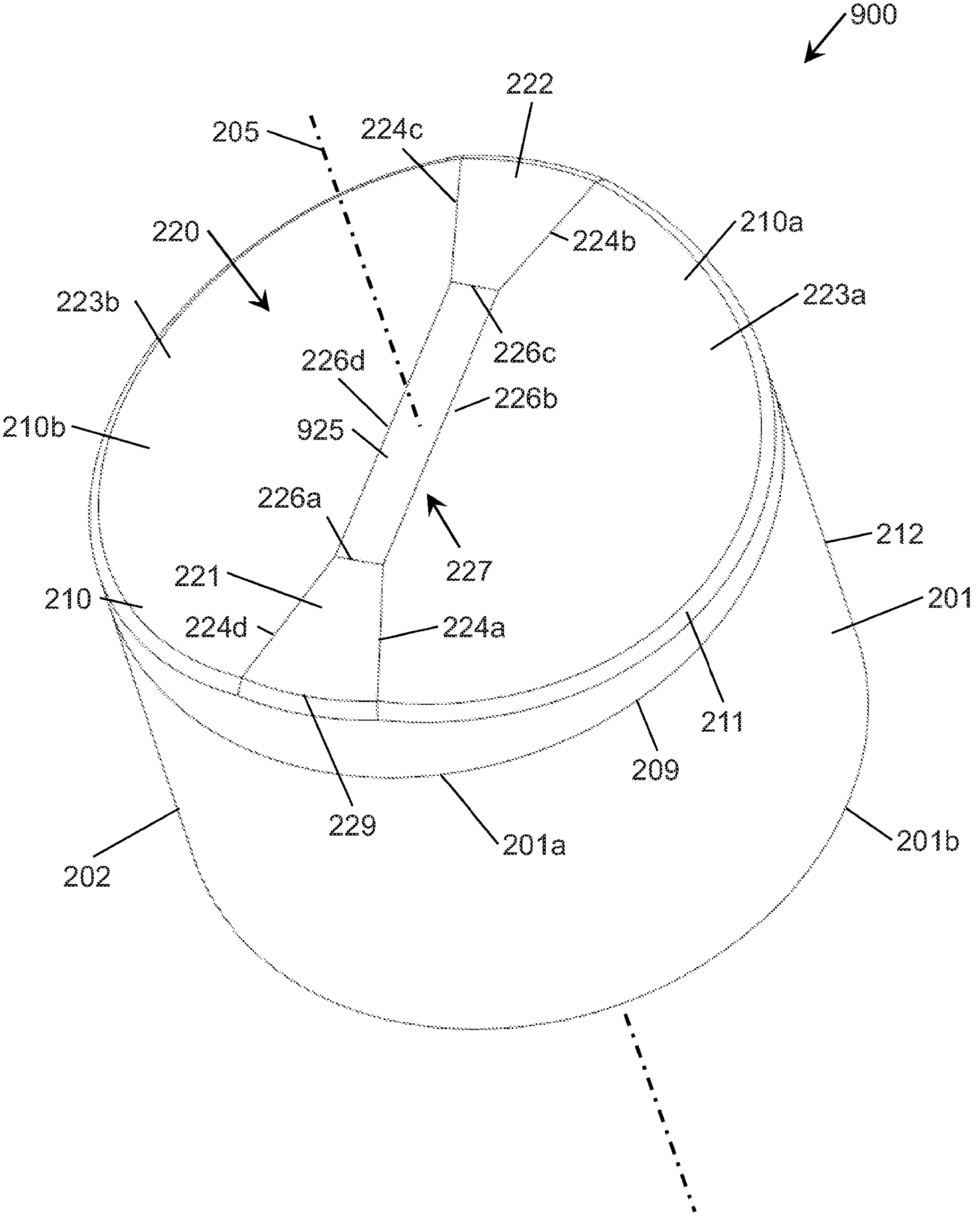
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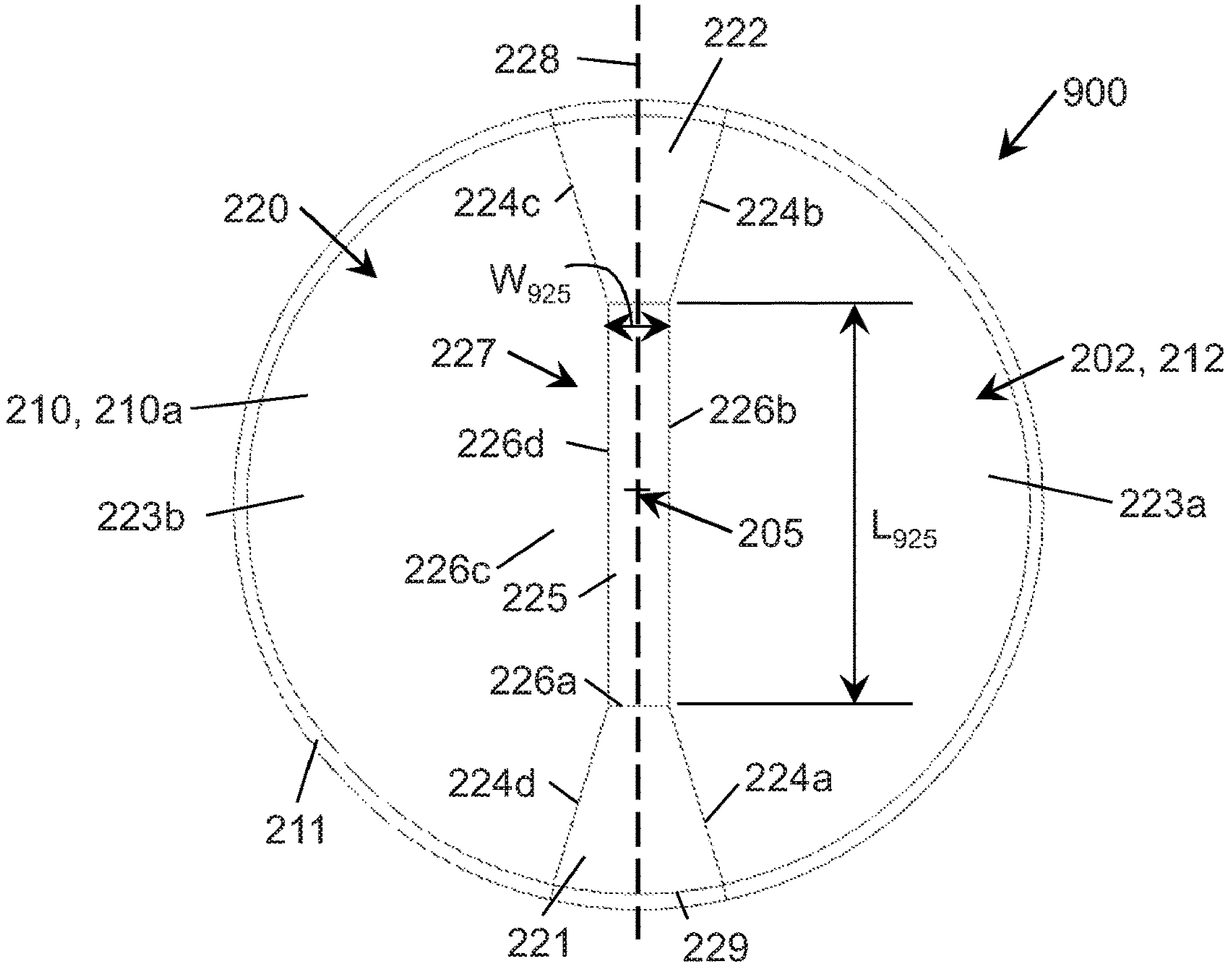
Figure 12A



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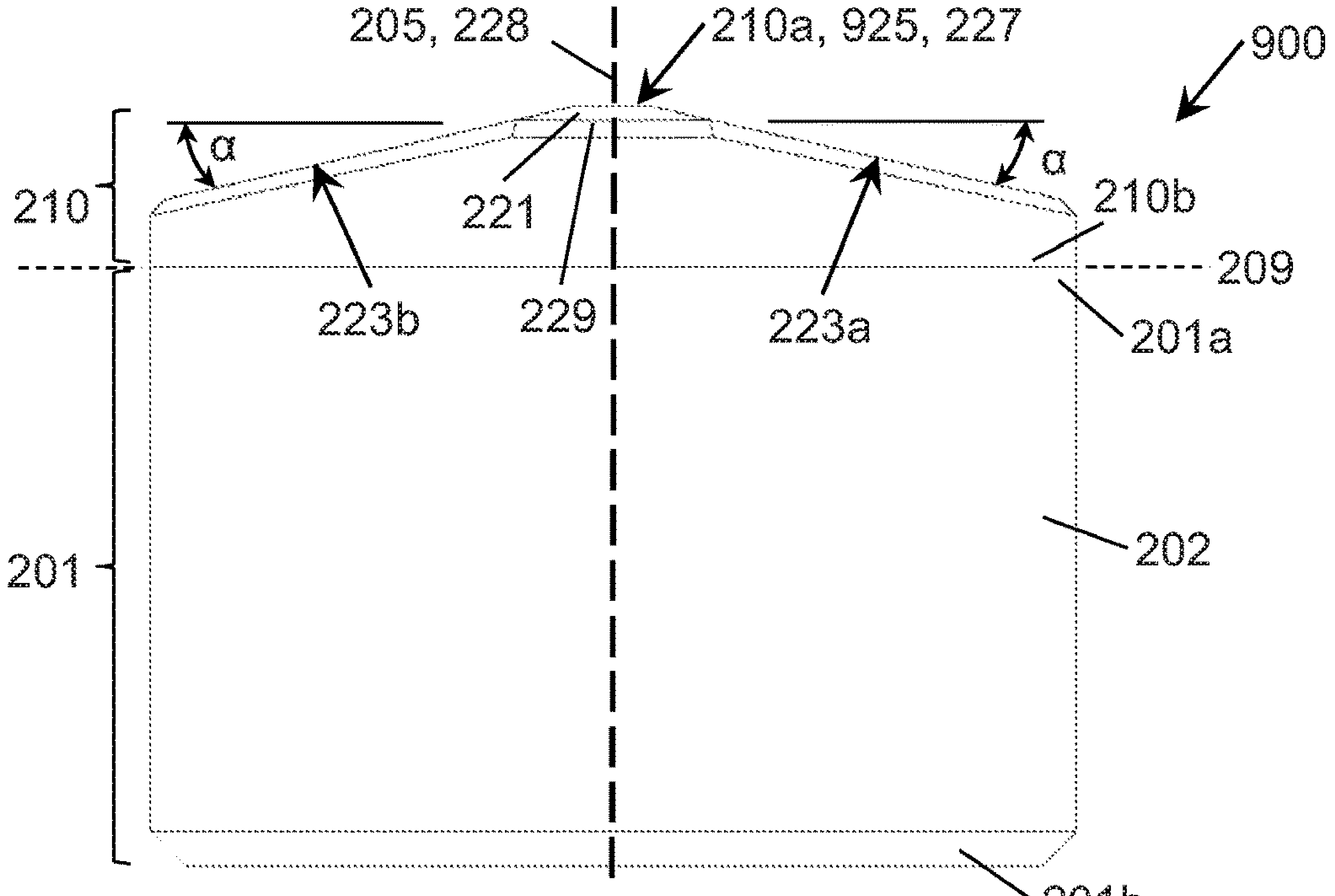

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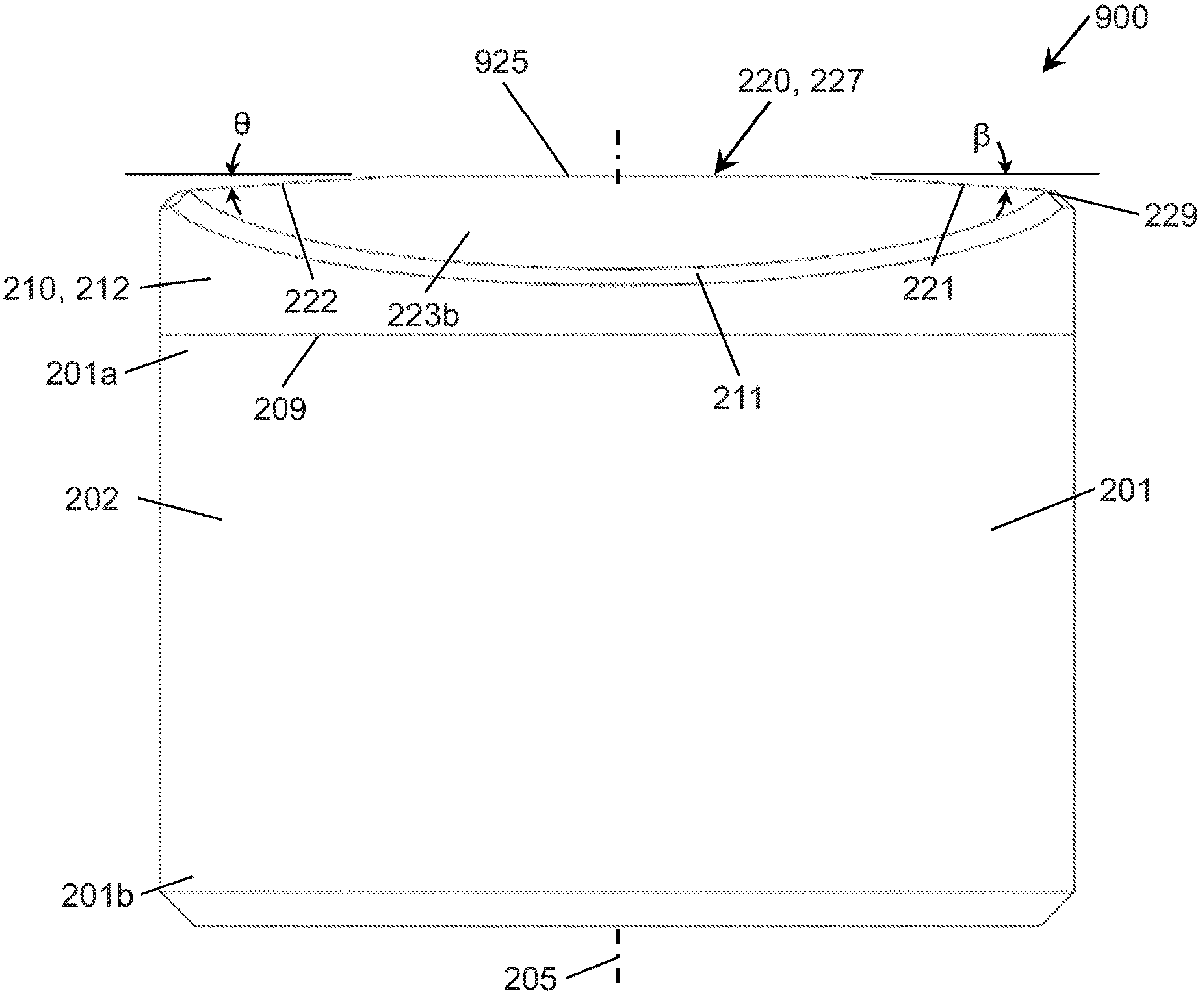
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205

Figure 12D

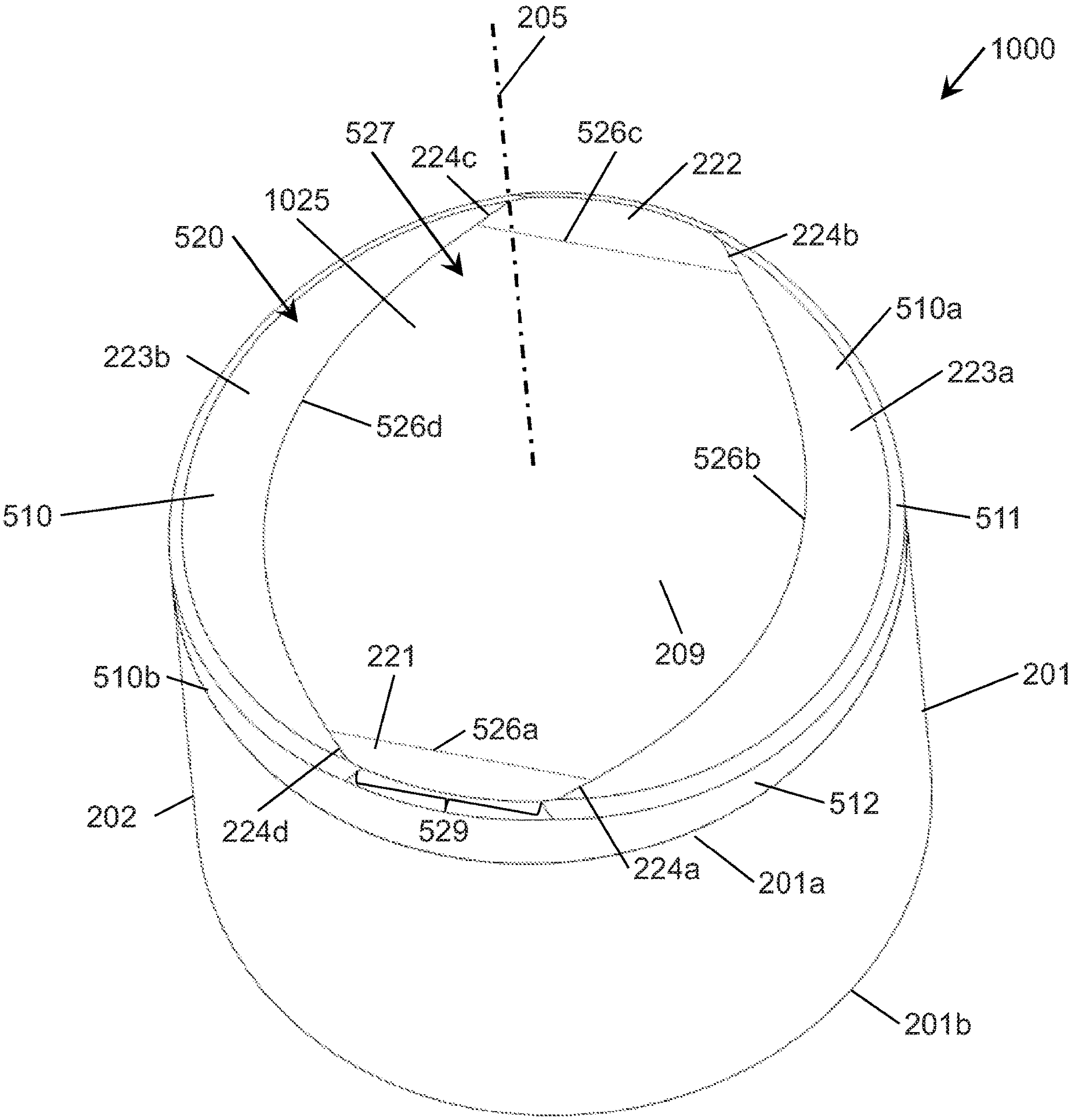

205
1000
527
224c
526c
222
1025
520
224b
510a
223b
223a
526d
526b
510
511
209
221
510b
201
526a
202
224d
529
512
224a
201a
201b

Figure 13A

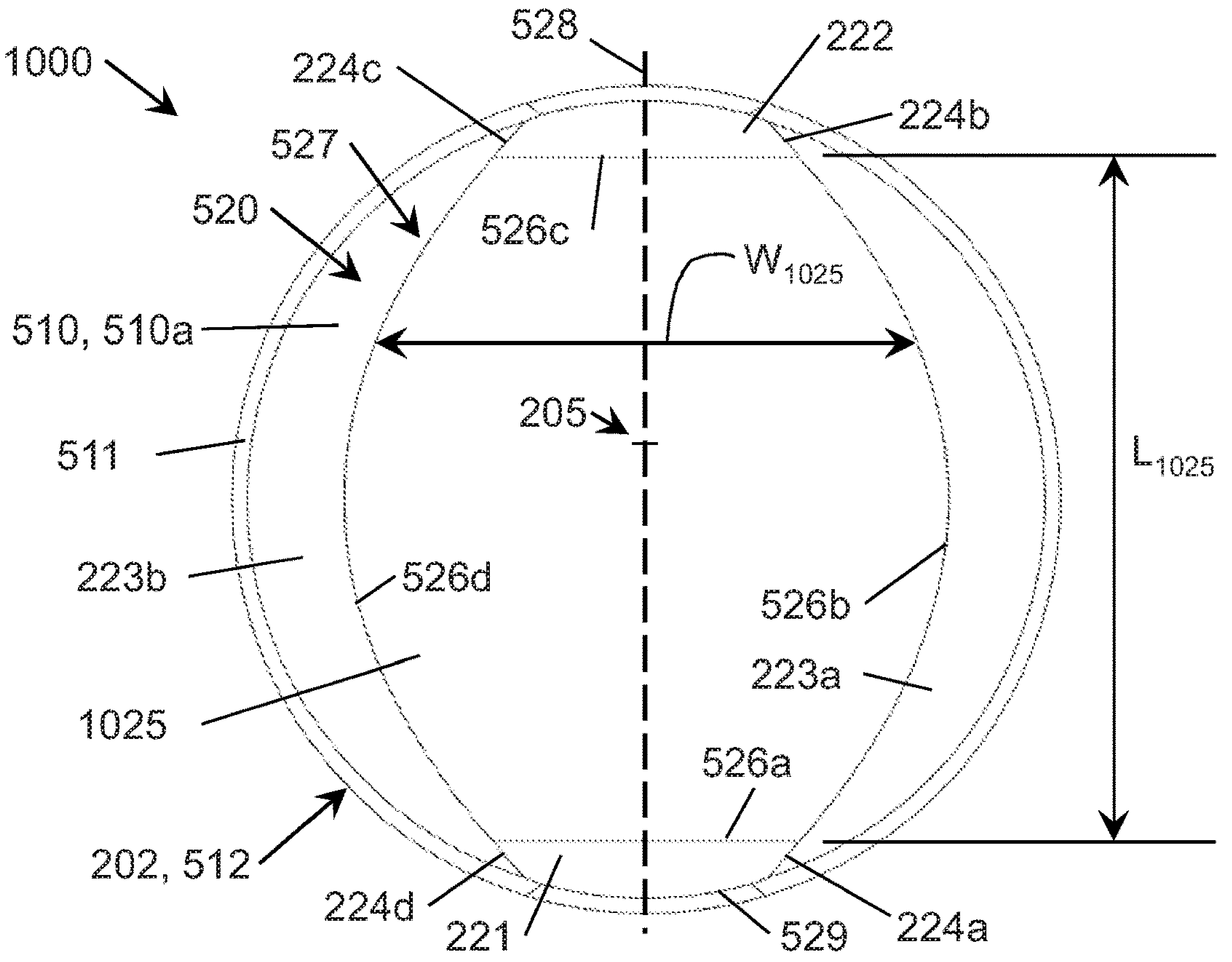


Figure 13B

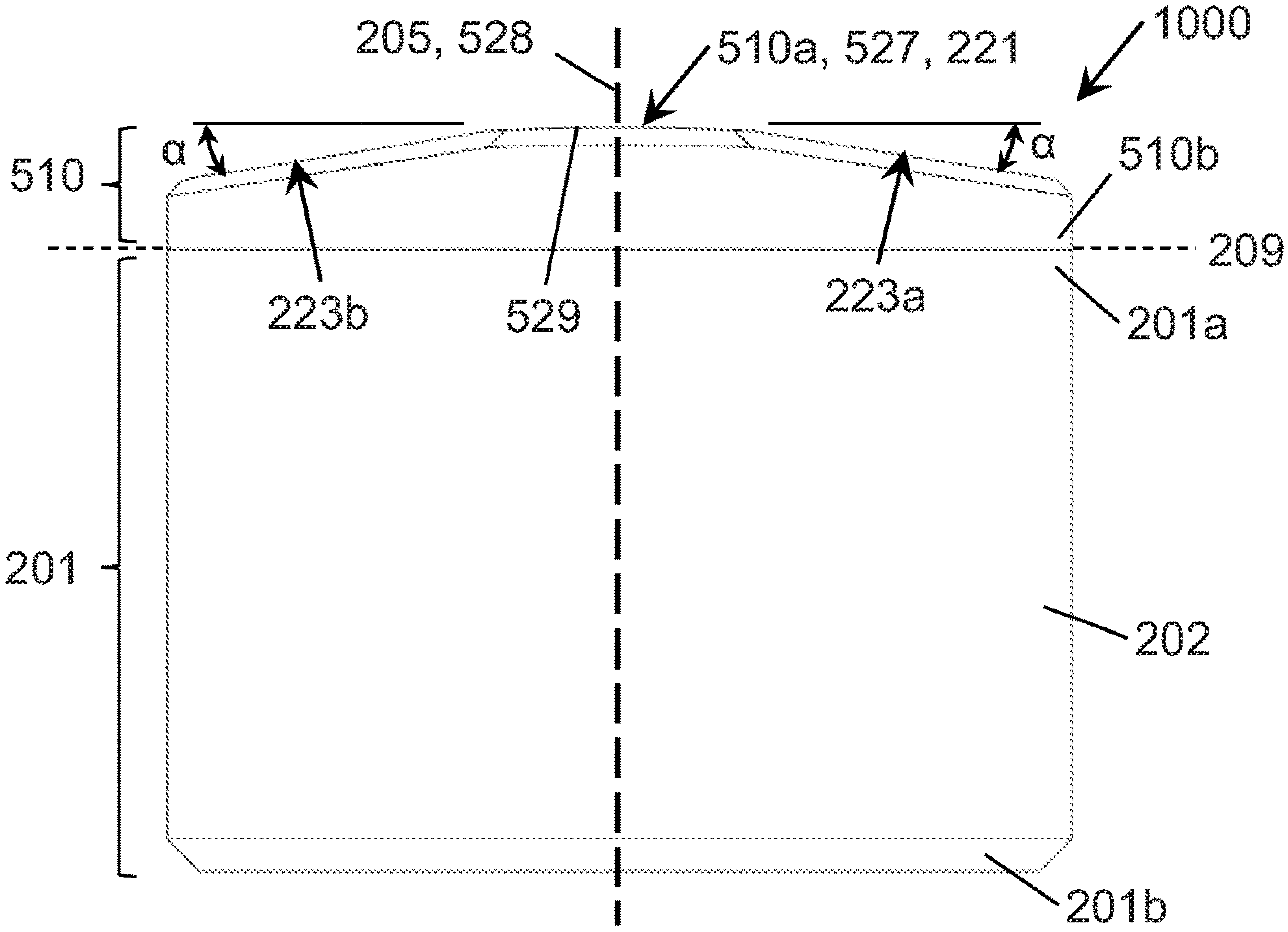
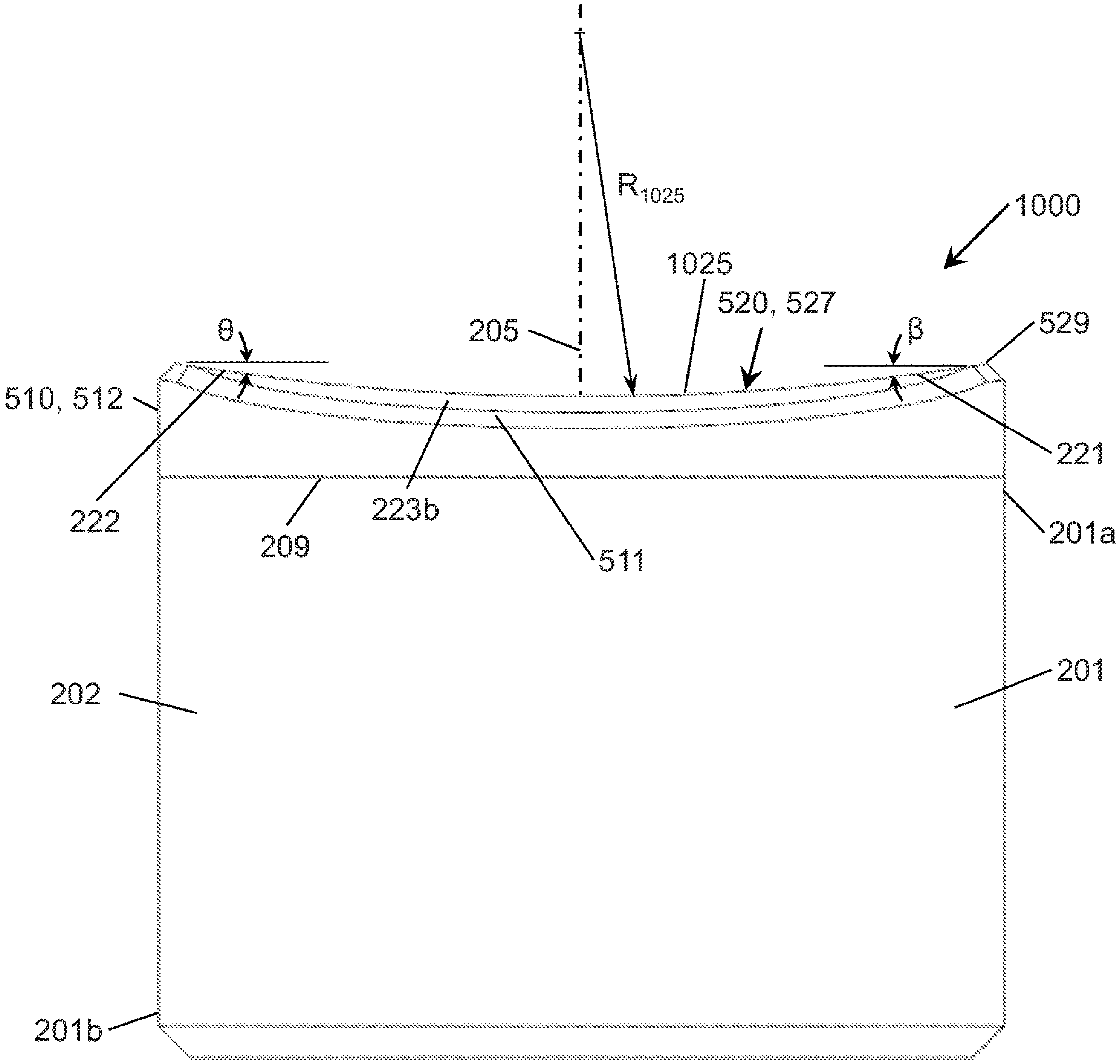


Figure 13C



R1025
1000
1025
520, 527
θ
205
β
529
510, 512
221
222
223b
209
511
201a
202
201
201b

Figure 13D

DRILL BIT CUTTER ELEMENTS AND DRILL BITS INCLUDING SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a 35 U.S.C. § 371 U.S. National Phase entry of PCT/US2019/050431 filed Sep. 10, 2019, and entitled "Drill Bit Cutter Elements and Drill Bits Including Same," which claims benefit of U.S. provisional patent application Ser. No. 62/729,382 filed Sep. 10, 2018, and entitled "Drill Bit Cutter Elements and Drill Bits Including same," each of which is hereby incorporated herein by reference in its entirety for all purposes.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not applicable.

BACKGROUND

The disclosure relates generally to drill bits for drilling a borehole in an earthen formation for the ultimate recovery of oil, gas, or minerals. More particularly, the disclosure relates to fixed cutter bits and cutter elements used on such bits.

An earth-boring drill bit is typically mounted on the lower end of a drill string and is rotated by rotating the drill string at the surface or by actuation of downhole motors or turbines, or by both methods. With weight applied to the drill string, the rotating drill bit engages the earthen formation and proceeds to form a borehole along a predetermined path toward a target zone. The borehole thus created will have a diameter generally equal to the diameter or "gage" of the drill bit.

Fixed cutter bits, also known as rotary drag bits, are one type of drill bit commonly used to drill boreholes. Fixed cutter bit designs include a plurality of blades angularly spaced about the bit face. The blades generally project radially outward along the bit body and form flow channels there between. In addition, cutter elements are often grouped and mounted on several blades. The configuration or layout of the cutter elements on the blades may vary widely, depending on a number of factors. One of these factors is the formation itself, as different cutter element layouts engage and cut the various strata with differing results and effectiveness.

The cutter elements disposed on the several blades of a fixed cutter bit are typically formed of extremely hard materials and include a layer of polycrystalline diamond ("PCD") material. In the typical fixed cutter bit, each cutter element or assembly comprises an elongate and generally cylindrical support member which is received and secured in a pocket formed in the surface of one of the several blades. In addition, each cutter element typically has a hard cutting layer of polycrystalline diamond or other superabrasive material such as cubic boron nitride, thermally stable diamond, polycrystalline cubic boron nitride, or ultrahard tungsten carbide (meaning a tungsten carbide material having a wear-resistance that is greater than the wear-resistance of the material forming the substrate) as well as mixtures or combinations of these materials. The cutting layer is exposed on one end of its support member, which is typically formed of tungsten carbide. For convenience, as used herein, the phrase "polycrystalline diamond cutter" or "PDC" may be used to refer to a fixed cutter bit ("PDC bit") or cutter element ("PDC cutter element") employing a hard cutting layer of polycrystalline diamond or other superabrasive material such as cubic boron nitride, thermally stable diamond, polycrystalline cubic boron nitride, or ultrahard tungsten carbide.

While the bit is rotated, drilling fluid is pumped through the drill string and directed out of the face of the drill bit. The fixed cutter bit typically includes nozzles or fixed ports spaced about the bit face that serve to inject drilling fluid into the flow passageways between the several blades. The flowing fluid performs several important functions. The fluid removes formation cuttings from the bit's cutting structure. Otherwise, accumulation of formation materials on the cutting structure may reduce or prevent the penetration of the cutting structure into the formation. In addition, the fluid removes cut formation materials from the bottom of the hole. Failure to remove formation materials from the bottom of the hole may result in subsequent passes by cutting structure to re-cut the same materials, thereby reducing the effective cutting rate and potentially increasing wear on the cutting surfaces. The drilling fluid and cuttings removed from the bit face and from the bottom of the hole are forced from the bottom of the borehole to the surface through the annulus that exists between the drill string and the borehole sidewall. Further, the fluid removes heat, caused by contact with the formation, from the cutter elements in order to prolong cutter element life. Thus, the number and placement of drilling fluid nozzles, and the resulting flow of drilling fluid, may significantly impact the performance of the drill bit.

Without regard to the type of bit, the cost of drilling a borehole for recovery of hydrocarbons may be very high and is proportional to the length of time it takes to drill to the desired depth and location. The time required to drill the well, in turn, is greatly affected by the cutting efficiency of the cutting structure on the drill bit. Accordingly, it is desirable to employ drill bits which will drill faster and longer, and which are usable over a wider range of formation hardness.

BRIEF SUMMARY OF THE DISCLOSURE

Embodiments of cutter elements for drill bits configured to drill boreholes in subterranean formations are disclosed herein. In one embodiment, a cutter element for a drill bit comprises a base portion having a central axis, a first end, a second end, and a radially outer cylindrical surface extending axially from the first end to the second end. In addition, the cutter element comprises a cutting layer fixably mounted to the first end of the base portion. The cutting layer includes a cutting face distal the base portion and a radially outer cylindrical surface extending axially from the cutting face to the radially outer cylindrical surface of the base portion. The radially outer cylindrical surface of the cutting layer is contiguous with the radially outer cylindrical surface of the base portion. The cutting face comprises an elongate raised ridge extending across the cutting face. The raised ridge has a first end at the radially outer cylindrical surface of the cutting layer and a second end at radially outer surface of the cutting layer. The raised ridge defines a maximum height of the cutter element measured axially from the second end of the base portion to the cutting face. The cutting face also comprises a first planar lateral side surface extending from the raised ridge to the radially outer cylindrical surface of the cutting layer, and a second planar lateral side surface extending from the raised ridge to the radially outer cylindrical surface of the cutting layer.

In another embodiment, a cutter element for a drill bit comprises a base portion having a central axis, a first end, a second end, and a radially outer surface extending axially from the first end to the second end. In addition, the cutter element comprises a cutting layer disposed at the first end of the base portion. The cutting layer includes a cutting face distal the base portion and a radially outer surface extending axially from the cutting face to the base portion. The cutting face comprises a planar central region. The cutting face also comprises a planar cutting region extending radially from the planar central region to the radially outer surface of the cutting layer. Further, the cutting face comprises a planar relief region extending radially from the planar central region to the radially outer surface of the cutting layer. Still further, the cutting face comprises a first planar lateral side region extending laterally from the planar central region, the planar cutting region, and the planar relief region to the radially outer surface of the cutting layer. Moreover, the cutting face comprises a second planar lateral side region extending laterally from the planar central region, the planar cutting region, and the planar relief region to the radially outer surface of the cutting layer. The first planar lateral side region slopes axially downward moving laterally from the planar central region, the planar cutting region, and the planar relief region toward the radially outer surface of the cutting layer. The second planar lateral side region slopes axially downward moving laterally from the planar central region, the planar cutting region, and the planar relief region to the radially outer surface of the cutting layer. The planar cutting region is circumferentially positioned between the first planar lateral side region and the second planar lateral side region. The planar relief region is circumferentially positioned between the first planar lateral side region and the second planar lateral side region. The central region is disposed between the first planar lateral side region and the second planar lateral side region.

Embodiments described herein comprise a combination of features and advantages intended to address various shortcomings associated with certain prior devices, systems, and methods. The foregoing has outlined rather broadly the features and technical advantages of the invention in order that the detailed description of the invention that follows may be better understood. The various characteristics described above, as well as other features, will be readily apparent to those skilled in the art upon reading the following detailed description, and by referring to the accompanying drawings. It should be appreciated by those skilled in the art that the conception and the specific embodiments disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the invention. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

For a detailed description of the preferred embodiments of the invention, reference will now be made to the accompanying drawings in which:

FIG. **1** is a schematic view of a drilling system including an embodiment of a drill bit with a plurality of cutter elements in accordance with the principles described herein;

FIG. **2** is a perspective view of the drill bit of FIG. **1**;

FIG. **3** is a face or bottom end view of the drill bit of FIG. **2**;

FIG. **4** is a partial cross-sectional view of the bit shown in FIG. **2** with the blades and the cutting faces of the cutter elements rotated into a single composite profile;

FIGS. **5**A-**5**E are perspective, top, front side, lateral side, and rear side views, respectively, of one of the cutter elements of the drill bit of FIG. **2**;

FIG. **5**F is a partial cross-sectional view of one of the cutter elements of FIG. **2** taken in section **5**F-**5**F of FIG. **5**B;

FIGS. **6**A-**6**D are perspective, top, front side, and lateral side views, respectively, of an embodiment of a cutter element in accordance with the principles described herein;

FIGS. **7**A-**7**E are perspective, top, front side, lateral side, and rear side views, respectively, of an embodiment of a cutter element in accordance with the principles described herein;

FIGS. **8**A-**8**E are perspective, top, front side, lateral side, and rear side views, respectively, of an embodiment of a cutter element in accordance with the principles described herein;

FIGS. **9**A-**9**E are perspective, top, front side, lateral side, and rear side views, respectively, of an embodiment of a cutter element in accordance with the principles described herein;

FIGS. **10**A-**10**D are perspective, top, front side, and lateral side views, respectively, of an embodiment of a cutter element in accordance with the principles described herein;

FIGS. **11**A-**11**D are perspective, top, front side, and lateral side views, respectively, of an embodiment of a cutter element in accordance with the principles described herein;

FIGS. **12**A-**12**D are perspective, top, front side, and lateral side views, respectively, of an embodiment of a cutter element in accordance with the principles described herein; and

FIGS. **13**A-**13**D are perspective, top, front side, and lateral side views, respectively, of an embodiment of a cutter element in accordance with the principles described herein.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following discussion is directed to various exemplary embodiments. However, one skilled in the art will understand that the examples disclosed herein have broad application, and that the discussion of any embodiment is meant only to be exemplary of that embodiment, and not intended to suggest that the scope of the disclosure, including the claims, is limited to that embodiment.

Certain terms are used throughout the following description and claims to refer to particular features or components. As one skilled in the art will appreciate, different persons may refer to the same feature or component by different names. This document does not intend to distinguish between components or features that differ in name but not function. The drawing figures are not necessarily to scale. Certain features and components herein may be shown exaggerated in scale or in somewhat schematic form and some details of conventional elements may not be shown in interest of clarity and conciseness.

In the following discussion and in the claims, the terms "including" and "comprising" are used in an open-ended fashion, and thus should be interpreted to mean "including, but not limited to . . . ." Also, the term "couple" or "couples" is intended to mean either an indirect or direct connection. Thus, if a first device couples to a second device, that connection may be through a direct connection, or through an indirect connection via other devices, components, and connections. In addition, as used herein, the terms "axial" and "axially" generally mean along or parallel to a central axis (e.g., central axis of a body or a port), while the terms "radial" and "radially" generally mean perpendicular to the central axis. For instance, an axial distance refers to a distance measured along or parallel to the central axis, and a radial distance means a distance measured perpendicular to the central axis. Any reference to up or down in the description and the claims will be made for purposes of clarity, with "up", "upper", "upwardly" or "upstream" meaning toward the surface of the borehole and with "down", "lower", "downwardly" or "downstream" meaning toward the terminal end of the borehole, regardless of the borehole orientation.

As previously described, the length of time it takes to drill to the desired depth and location impacts the cost of drilling operations. The shape and positioning of the cutter elements impact bit durability and rate of penetration (ROP) and thus, are important to the success of a particular bit design. Embodiments described herein are directed to cutter elements for fixed cutter drill bits with geometries that offer the potential to improve bit durability and/or ROP. In some embodiments, cutter elements disclosed herein can be reused after the initial cutting edge is sufficiently worn, which offers the potential to enhance the useful life of such cutter elements.

Referring now to FIG. **1**, a schematic view of an embodiment of a drilling system **10** in accordance with the principles described herein is shown. Drilling system **10** includes a derrick **11** having a floor **12** supporting a rotary table **14** and a drilling assembly **90** for drilling a borehole **26** from derrick **11**. Rotary table **14** is rotated by a prime mover such as an electric motor (not shown) at a desired rotational speed and controlled by a motor controller (not shown). In other embodiments, the rotary table (e.g., rotary table **14**) may be augmented or replaced by a top drive suspended in the derrick (e.g., derrick **11**) and connected to the drillstring (e.g., drillstring **20**).

Drilling assembly **90** includes a drillstring **20** and a drill bit **100** coupled to the lower end of drillstring **20**. Drillstring **20** is made of a plurality of pipe joints **22** connected end-to-end, and extends downward from the rotary table **14** through a pressure control device **15**, such as a blowout preventer (BOP), into the borehole **26**. The pressure control device **15** is commonly hydraulically powered and may contain sensors for detecting certain operating parameters and controlling the actuation of the pressure control device **15**. Drill bit **100** is rotated with weight-on-bit (WOB) applied to drill the borehole **26** through the earthen formation. Drillstring **20** is coupled to a drawworks **30** via a kelly joint **21**, swivel **28**, and line **29** through a pulley. During drilling operations, drawworks **30** is operated to control the WOB, which impacts the rate-of-penetration of drill bit **100** through the formation. In this embodiment, drill bit **100** can be rotated from the surface by drillstring **20** via rotary table **14** and/or a top drive, rotated by downhole mud motor **55** disposed along drillstring **20** proximal bit **100**, or combinations thereof (e.g., rotated by both rotary table **14** via drillstring **20** and mud motor **55**, rotated by a top drive and the mud motor **55**, etc.). For example, rotation via downhole motor **55** may be employed to supplement the rotational power of rotary table **14**, if required, and/or to effect changes in the drilling process. In either case, the rate-of-penetration (ROP) of the drill bit **100** into the borehole **26** for a given formation and a drilling assembly largely depends upon the WOB and the rotational speed of bit **100**.

During drilling operations a suitable drilling fluid **31** is pumped under pressure from a mud tank **32** through the drillstring **20** by a mud pump **34**. Drilling fluid **31** passes from the mud pump **34** into the drillstring **20** via a desurger **36**, fluid line **38**, and the kelly joint **21**. The drilling fluid **31** pumped down drillstring **20** flows through mud motor **55** and is discharged at the borehole bottom through nozzles in face of drill bit **100**, circulates to the surface through an annular space **27** radially positioned between drillstring **20** and the sidewall of borehole **26**, and then returns to mud tank **32** via a solids control system **36** and a return line **35**. Solids control system **36** may include any suitable solids control equipment known in the art including, without limitation, shale shakers, centrifuges, and automated chemical additive systems. Control system **36** may include sensors and automated controls for monitoring and controlling, respectively, various operating parameters such as centrifuge rpm. It should be appreciated that much of the surface equipment for handling the drilling fluid is application specific and may vary on a case-by-case basis.

Referring now to FIGS. **2** and **3**, drill bit **100** is a fixed cutter bit, sometimes referred to as a drag bit, and is designed for drilling through formations of rock to form a borehole. Bit **100** has a central or longitudinal axis **105**, a first or uphole end **100***a*, and a second or downhole end **100***b*. Bit **100** rotates about axis **105** in the cutting direction represented by arrow **106**. In addition, bit **100** includes a bit body **110** extending axially from downhole end **100***b*, a threaded connection or pin **120** extending axially from uphole end **100***a*, and a shank **130** extending axially between pin **120** and body **110**. Pin **120** couples bit **100** to drill string **20**, which is employed to rotate the bit **100** to drill the borehole **26**. Bit body **110**, shank **130**, and pin **120** are coaxially aligned with axis **105**, and thus, each has a central axis coincident with axis **105**.

The portion of bit body **110** that faces the formation at downhole end **100***b* includes a bit face **111** provided with a cutting structure **140**. Cutting structure **140** includes a plurality of blades **141**, **142**, which extend from bit face **111**. In this embodiment, cutting structure **140** includes three angularly spaced-apart primary blades **141**, and three angularly spaced apart secondary blades **142**. Further, in this embodiment, the plurality of blades (e.g., primary blades **141**, and secondary blades **142**) are uniformly angularly spaced on bit face **111** about bit axis **105**. In this embodiment, bit **100** includes five total blades **141**, **142**—three primary blades **141** and two secondary blades **142**. The five blades **141**, **142** are uniformly angularly spaced about 72° apart. In other embodiments, the blades (e.g., blades **141**, **142** may be non-uniformly circumferentially spaced about bit face **111**). Although bit **100** is shown as having three primary blades **141** and two secondary blades **142**, in other embodiments, the bit (e.g., bit **100**) may comprise any suitable number of primary and secondary blades such as two primary blades and four secondary blades or three primary blades and three secondary blades.

In this embodiment, primary blades **141** and secondary blades **142** are integrally formed as part of, and extend from, bit body **110** and bit face **111**. Primary blades **141** and secondary blades **142** extend generally radially along bit face **111** and then axially along a portion of the periphery of bit **100**. In particular, primary blades **141** extend radially from proximal central axis **105** toward the periphery of bit body **110**. Primary blades **141** and secondary blades **142** are separated by drilling fluid flow courses **143**. Each blade **141**, **142** has a leading edge or side **141***a*, **142***a*, respectively, and a trailing edge or side **141***b*, **142***b*, respectively, relative to the direction of rotation **106** of bit **100**.

Referring still to FIGS. **2** and **3**, each blade **141**, **142** includes a cutter-supporting surface **144** for mounting a plurality of cutter elements **200**. In particular, cutter elements **200** are arranged adjacent one another in a radially extending row proximal the leading edge of each primary blade **141** and each secondary blade **142**. In this embodiment, each cutter element **200** has substantially the same size and geometry, which will be described in more detail below.

As will also be described in more detail below, each cutter element **200** has a cutting face **220**. In the embodiments described herein, each cutter element **200** is mounted such that its cutting face **220** is generally forward-facing. As used herein, "forward-facing" is used to describe the orientation of a surface that is substantially perpendicular to, or at an acute angle relative to, the cutting direction of the bit (e.g., cutting direction **106** of bit **100**).

Referring still to FIGS. **2** and **3**, bit body **110** further includes gage pads **147** of substantially equal axial length measured generally parallel to bit axis **105**. Gage pads **147** are circumferentially-spaced about the radially outer surface of bit body **110**. Specifically, one gage pad **147** intersects and extends from each blade **141**, **142**. In this embodiment, gage pads **147** are integrally formed as part of the bit body **110**. In general, gage pads **147** can help maintain the size of the borehole by a rubbing action when cutter elements **200** wear slightly under gage. Gage pads **147** also help stabilize bit **100** against vibration.

Referring now to FIG. **4**, an exemplary profile of bit body **110** is shown as it would appear with blades **141**, **142** and cutting faces **220** rotated into a single rotated profile. In rotated profile view, blades **141**, **142** of bit body **110** form a combined or composite blade profile **148** generally defined by cutter-supporting surfaces **144** of blades **141**, **142**. In this embodiment, the profiles of surfaces **144** of blades **141**, **142** are generally coincident with each other, thereby forming a single composite blade profile **148**.

Composite blade profile **148** and bit face **111** may generally be divided into three regions conventionally labeled cone region **149***a*, shoulder region **149***b*, and gage region **149***c*. Cone region **149***a* comprises the radially innermost region of bit body **110** and composite blade profile **148** extending from bit axis **105** to shoulder region **149***b*. In this embodiment, cone region **149***a* is generally concave. Adjacent cone region **149***a* is the generally convex shoulder region **149***b*. The transition between cone region **149***a* and shoulder region **149***b*, typically referred to as the nose **149***d*, occurs at the axially outermost portion of composite blade profile **148** where a tangent line to the blade profile **148** has a slope of zero. Moving radially outward, adjacent shoulder region **149***b* is the gage region **149***c* which extends substantially parallel to bit axis **105** at the outer radial periphery of composite blade profile **148**. As shown in composite blade profile **148**, gage pads **147** define the gage region **149***c* and the outer radius R_{110} of bit body **110**. Outer radius R_{110} extends to and therefore defines the full gage diameter of bit body **110**. As used herein, the term "full gage diameter" refers to elements or surfaces extending to the full, nominal gage of the bit diameter.

Referring now to FIGS. **4** and **5**, moving radially outward from bit axis **105**, bit face **111** includes cone region **149***a*, shoulder region **149***b*, and gage region **149***c* as previously described. Primary blades **141** extend radially along bit face **111** from within cone region **149***a* proximal bit axis **105** toward gage region **149***c* and outer radius R_{110}. Secondary blades **142** extend radially along bit face **111** from proximal nose **149***d* toward gage region **149***c* and outer radius R_{110}. Thus, in this embodiment, each primary blade **141** and each secondary blade **142** extends substantially to gage region **149***c* and outer radius R_{110}. In this embodiment, secondary blades **142** do not extend into cone region **149***a*, and thus, secondary blades **142** occupy no space on bit face **111** within cone region **149***a*. Although a specific embodiment of bit body **110** has been shown in described, one skilled in the art will appreciate that numerous variations in the size, orientation, and locations of the blades (e.g., primary blades **141**, secondary blades, **142**, etc.), and cutter elements (e.g., cutter elements **200**) are possible.

As best shown in FIG. **4**, bit **100** includes an internal plenum **104** extending axially from uphole end **100***a* through pin **120** and shank **130** into bit body **110**. Plenum **104** permits drilling fluid to flow from the drill string **20** into bit **100**. Body **110** is also provided with a plurality of flow passages **107** extending from plenum **104** to downhole end **100***b*. A nozzle **108** is seated in the lower end of each flow passage **107**. Together, passages **107** and nozzles **108** distribute drilling fluid around cutting structure **140** to flush away formation cuttings and to remove heat from cutting structure **140**, and more particularly cutting elements **145**, during drilling.

Referring now to FIGS. **5**A-**5**E, one cutter element **200** is shown. Although only one cutter element **200** is shown in FIGS. **5**A-**5**D, it is to be understood that all cutter elements **200** of bit **100** are the same. In general, bit **100** may include any number of cutter elements **200**, and further, cutter elements **200** can be used in connection with different cutter elements (e.g., cutter elements having geometries different than cutter element **200**) on bit **100**.

In this embodiment, cutter element **200** includes a base or substrate **201** and a cutting disc or layer **210** bonded to the substrate **201**. Cutting layer **210** and substrate **201** meet at a reference plane of intersection **209** that defines the location at which substrate **201** and cutting layer **210** are fixably attached. In this embodiment, substrate **210** is made of tungsten carbide and cutting layer **210** is made of an ultrahard material such as polycrystalline diamond (PCD) or other superabrasive material. Part and/or all of the diamond in cutting layer **210** may be leached, finished, polished, and/or otherwise treated to enhance durability, efficiency and/or effectiveness. While cutting layer **210** is shown as a single layer of material mounted to substrate **210**, in general, the cutting layer (e.g., layer **210**) may be formed of one or more layers of one or more materials. In addition, although substrate **201** is shown as a single, homogenous material, in general, the substrate (e.g., substrate **201**) may be formed of one or more layers of one or more materials.

Substrate **201** has a central axis **205**, a first end **201***a* bonded to cutting layer **210** at an interface disposed in a plane of intersection **209**, a second end **201***b* opposite end **201***a* and distal cutting layer **210**, and a radially outer surface **202** extending axially between ends **201***a*, **201***b*. In this embodiment, substrate **201** is generally cylindrical, and thus, outer surface **202** is generally cylindrical.

Referring still to FIGS. **5**A-**5**E, cutting layer **210** has a first end **210***a* distal substrate **201**, a second end **210***b* bonded to end **201***a* of substrate **201** at plane of intersection **209**, and a radially outer surface **212** extending axially between ends **210***a*, **210***b*. In this embodiment, cutting layer **210** is generally disc-shaped, and thus, outer surface **212** is generally cylindrical. In addition, outer surfaces **202, 212** are coextensive and contiguous such that there is a generally smooth transition moving axially between outer surfaces **202, 212**.

The outer surface of cutting layer **210** at first end **210***a* defines the cutting face **220** of cutter element **200** and is designed and shaped to engage and shear the formation during drilling operations. In this embodiment, a chamfer or bevel **211** is provided at the intersection of cutting face **220** and outer surface **212** about the entire outer periphery of cutting face **220**.

In this embodiment, cutting face **220** is generally convex or bowed outward in the front side view (FIG. **5**C) and the lateral side view (FIG. **5**D). In addition, in this embodiment, cutting face **220** is defined by a plurality of discrete regions or surfaces that intersect at linear boundaries or edges. More specifically, as best shown in FIGS. **5**A and **5**B, cutting face **220** includes a central region or surface **225**, a cutting region or surface **221** extending radially from central region **225** to outer surface **212**, a relief region or surface **222** extending radially from central region **225** to outer surface **212**, and a pair of lateral side regions or surfaces **223***a*, **223***b* extending from regions **225**, **221**, **222** to outer surface **212**. Regions **221**, **222**, **223***a*, **223***b* are circumferentially disposed about axis **205** and central region **225**. In addition, regions **221**, **222**, **223***a*, **223***b* are positioned circumferentially adjacent each other with each region **221**, **222** circumferentially disposed between regions **223***a*, **223***b* and each region **223***a*, **223***b* circumferentially disposed between regions **221**, **222**. Thus, region **221** extends circumferentially from region **223***a* to region **223***b*, region **222** extends circumferentially from region **223***a* to region **223***b*, region **223***a* extends circumferentially from region **221** to region **222**, and region **223***b* extends circumferentially from region **221** to region **222**. In this embodiment, the centerlines of regions **223***a*, **223***b* are angularly spaced 180° apart about axis **205** and the centerlines of regions **221**, **222** are angularly spaced 180° apart about axis **205**. Accordingly, regions **221**, **222** extend radially in opposite directions from central region **225** to outer surface **212** and regions **223***a*, **223***b* extend radially in opposite directions from central region **225** to outer surface **212**.

A linear boundary or edge is provided at the intersection of each circumferentially adjacent region **221**, **222**, **223***a*, **223***b*. As shown in FIGS. **5**A and **5**B, regions **221**, **223***a* intersect at a linear edge **224***a*, regions **223***a*, **222** intersect at a linear edge **224***b*, regions **222**, **223***b* intersect at a linear edge **224***c*, and regions **223***b*, **221** intersect at a linear edge **224***d*. Each linear edge **224***a*, **224***b*, **224***c*, **224***d* extends from central region **225** to outer surface **212**. As best shown in the top view of cutter element **200** in FIG. **5**B (looking at cutting face **220** as viewed parallel to central axis **205**), in this embodiment, linear edges **224***a*, **224***d* taper or slope away from each other moving radially along cutting region **221** from central region **225** to outer surface **212**, and linear edges **224***b*, **224***c* taper or slope away from each other moving radially along relief region **222** from central region **225** to outer surface **212**. As a result, cutting region **221** has a width measured perpendicular to a reference plane **228** containing central axis **205** in top view that increases moving radially from central region **225** to outer surface **212**, and similarly, relief region **222** has a width measured perpendicular to reference plane **228** in top view that increases moving radially from central region **225** to outer surface **212**. However, in other embodiments, the width of the cutting region (e.g., cutting region **221**) and the width of the relief region (e.g., relief region **222**) may increase, decrease, or remain constant moving radially outward from the central region (e.g., central region **225**) to the outer surface (e.g., outer surface **212**).

Referring still to FIGS. **5**A-**5**E, central region **225** is radially centered on cutting face **220** and centered relative to axis **205**. In particular, axis **205** intersects the geometric center of central region **225**. In this embodiment, central surface or region **225** is planar, and thus, may also be referred to as "planar" surface or facet. In addition, in this embodiment, central region **225** is oriented perpendicular to axis **205** and is rectangular. A linear boundary or edge is provided at the intersection of central region **225** and each region **221**, **222**, **223***a*, **223***b*. As best shown in FIGS. **5**A and **5**B, regions **225**, **221** intersect at a linear edge **226***a*, regions **225**, **223***a* intersect at a linear edge **226***b*, regions **225**, **222** intersect at a linear edge **226***c*, and regions **225**, **223***b* intersect at a linear edge **226***d*. Linear edge **226***a*, **226***b*, **226***c*, **226***d* defined the four sides of the rectangular central region **225**, and each linear edge **224***a*, **224***b*, **224***c*, **224***d* extends from one corner of the rectangular central region **225**.

In this embodiment, each cutting surface or region **221**, **222**, **223***a*, **223***b* on cutting face **220** is planar, and thus, each may be referred to as a "planar" surface or facet. As best shown in the front side view (FIG. **5**C) and rear side view (FIG. **5**E) (looking at cutting face **220** perpendicular to axis **205** and parallel to lateral facets **223***a*, **223***b*), in embodiments described herein, each lateral facet **223***a*, **223***b* slopes axially toward base **201** moving radially outward from facets **225**, **221**, **222** to outer surface **212**. In particular, each lateral facet **223***a*, **223***b* is oriented at a non-zero acute angle α measured from the lateral facet **223***a*, **223***b* to a reference plane oriented perpendicular to central axis **205** in the front side view and the rear side view. In embodiments described herein, each angle α is less than 45°, preferably ranges from 5° to 25°, and more preferably ranges from 14° to 15°. In general, angles α can be the same or different. In this embodiment, angles α are the same, and further, each angle α is 14.5°.

As best shown in the lateral side view (FIG. **5**D) (looking at cutting face **220** perpendicular to axis **205** and parallel to cutting face **221** and relief facet **222**), in this embodiment, cutting facet **221** slopes axially toward base **201** moving radially outward from central facet **225** to outer surface **212** and relief facet **222** slopes axially toward base **201** moving radially outward from central facet **225** to outer surface **212**. In particular, cutting facet **221** is oriented at a non-zero acute angle β measured from facet **221** to a reference plane oriented perpendicular to central axis **205** in the lateral side view, and relief facet **222** is oriented at a non-zero acute angle β measured from facet **222** to a reference plane oriented perpendicular to the central axis **205** in the lateral side view. Each angle β, θ is less than 45°, preferably ranges from 1° to 20°, and more preferably ranges from 2° to 10°. In general, angles β, θ can be the same or different. In this embodiment, angles β, θ are the same, and further, each angle β is 4° and angle θ is 4°. Although both facets **221**, **222** slope toward base **201** moving radially outward from central facet **225** to outer surface **212** in this embodiment, in other embodiments, one or both facets **221**, **222** can slope away from base **201** moving radially outward from central facet **225** to outer surface **212**.

As best shown in FIG. **5**B, central region **225** has a length L_{225} measured parallel to plane **228** from edge **226***a* to edge **226***c* in top view, and a width W_{225} measured perpendicular to plane **228** from edge **226***b* to edge **226***d* in top view. In this embodiment, central region **225** is rectangular with linear edges **226***a*, **226***c* oriented parallel to each other and linear edges **226***b*, **226***d* oriented parallel to each other, and thus, the length L_{225} measured between edges **226***a*, **226***c* is constant at all points along edges **226***a*, **226***c*, and further, the width W_{225} measured between edges **226***b*, **226***d* is constant at all points along edges **226***b*, **226***d*. The geometry of central region **225** may be characterized by the ratio of the length L_{225} to the diameter of cutter element **200** and an "aspect ratio" that is equal to the ratio of the length L_{225} to the width W_{225}. In general, the diameter of a cutter element is the diameter of the base or substrate of the cutter element (e.g., the diameter of substrate **201**). The ratio of the length L_{225} to the diameter of cutter element **200** is less than 1.0, preferably between 0.10 and 0.90, more preferably between 0.20 and 0.80, and even more preferably between 0.25 and 0.75, and still even more preferably between 0.33 and 0.66; and the aspect ratio of central region **225** is preferably less than 50.0, more preferably between 0.10 and 30.0, more preferably between 0.50 and 30.0, even more preferably between 1.0 and 10.0, and still even more preferably between 1.0 and 5.0. In some embodiments, the aspect ratio of the central region (e.g., central region **225**) is between 0.25 and 10.0. In this embodiment, the aspect ratio of central region **225** is 1.37.

Referring now to FIGS. **5**A-**5**D, in this embodiment, a pair of planar surfaces or flats **230***a*, **230***b* extend across radially outer surfaces **202**, **212** of substrate **201** and cutting layer **210**, respectively. Each flat **230***a*, **230***b* extends axially from cutting face **220** along outer surface **212** of cutting layer **201** and across plane of intersection **209** into and along outer surface **202** of substrate **201**. However, in this embodiment, flats **230***a*, **230***b* do not extend to second end **201***b* of substrate **201**. Rather, flats **230***a*, **230***b* terminate proximal but axially spaced from end **201***b*. Each flat **230***a*, **230***b* is contiguous and smooth as it extends across outer surfaces **212**, **202**.

Flats **230***a*, **230***b* are circumferentially spaced along outer surfaces **202**, **212**, and generally positioned on opposite circumferential sides of cutting facet **221**. Flat **230***a* circumferentially spans a portion of cutting facet **221** and lateral facet **223***a* along outer surface **212** and flat **230***b* circumferentially spans a portion of cutting facet **221** and lateral facet **223***b*. In this embodiment, each flat **230***a*, **230***b* is oriented perpendicular to a plane P_{230a}, P_{230b}, respectively, containing the central axis **205**. Planes P_{230a}, P_{230b} are angularly spaced apart about axis **205** by an angle μ that is less than 180°, preferably 70° to 120°, and more preferably 80° to 100°. In this embodiment, angle μ is 90°. Further, each flat **230***a*, **230***b* generally slopes radially outward moving axially from its end at cutting face **220** to its end along substrate **201**. More specifically, FIG. **5**F illustrates a partial cross-section of cutter element **200** taken in section **5**F-**5**F of FIG. **5**B. Section **5**F-**5**F lies in reference plane P_{230a}, and thus, FIG. **5**F illustrates a partial cross-section of cutter element **200** as viewed perpendicular to plane P_{230a} and parallel to flat **230***a*. As shown in FIG. **5**F, flat **230***a* is oriented at an acute angle σ measured in plane P_{230a} between central axis **205** and flat **230***a*. Angle σ is preferably 2° to 10°, and more preferably 6° to 8°. In this embodiment, angle σ is 7°. Although FIG. **5**F illustrates the slope angle σ of flat **230***a*, it should be appreciated that flat **230***b* is similarly configured and oriented. In general, both flats **230***a*, **230***b* can be oriented at the same angle σ or different angles σ. In this embodiment, both flats **230***a*, **230***b* are oriented at the same angle σ of 7° measured in the corresponding plane P_{230a}, P_{230b} relative to central axis **205**. However, in other embodiments, the angle the angle σ between each flat **230***a*, **230***b* relative to central axis **205** measured in plane P_{230a}, P_{230b}, respectively, may be different.

Referring to FIGS. **5**A-**5**D, as previously described, lateral facets **223***a*, **223***b* slope axially downward toward substrate **201** moving from regions **221**, **225**, **222** to outer surface **212**. As a result, regions **221**, **225**, **222** define an elongate, generally raised ridge or crown **227** extending linearly completely across cutting face **220**. Thus, ridge **227** may be described as having a first end at outer surface **212** at one side of cutter element **200** and a second end at outer surface **212** at the radially opposite side of cutter element **200**. Ridge **227** (or at least a portion thereof) defines the maximum height of cutter element **200** measured axially from end **201***b* to cutting face **220** at end **210***a*.

As best shown in the top view of cutter element **200** in FIG. **5**B (looking at cutting face **220** as viewed parallel to central axis **205**), in this embodiment, cutting face **220** is symmetric about the reference plane **228** that contains central axis **205**, is disposed between lateral regions **223***a*, **223***b*, and bisects crown **227** and regions **221**, **222**. In this embodiment, planes P_{230a}, P_{230b} are equally angularly spaced from plane **228** (on opposite directions from plane **228**). Thus, the angle between planes **228**, P_{230a} is ½ the angle μ and the angle between planes **228**, P_{230b} is ½ the angle μ.

Referring again to FIGS. **2** and **3**, cutting elements **200** are mounted in bit body **110** such that cutting faces **220** are exposed to the formation material, and further, such that cutting faces **220** are oriented so that cutting edges **229**, flats **230***a*, **230***b*, and regions **221**, **222**, **223***a*, **223***b*, **225** are positioned to perform their distinct functional roles in abrading/shearing, excavating, and removing rock from beneath the drill bit **110** during rotary drilling operations. More specifically, each cutter element **200** is mounted to a corresponding blade **141**, **142** with substrate **201** received and secured in a pocket formed in the cutter support surface **144** of the blade **141**, **142** to which it is fixed by brazing or other suitable means. Each cutter element **200** is oriented with axis **205** oriented generally parallel or tangent to cutting direction **106** and such that the corresponding cutting face **220** is exposed and leads the cutter element **200** relative to cutting direction **106** of bit **100**. As previously described, cutting faces **220** are forward-facing. In addition, each cutter element **200** is oriented with plane **228** oriented perpendicular to the cutter support surface **144**, cutting region **221** distal the corresponding cutter support surface **144**, and relief region **222** proximal the corresponding cutter support surface **144**. Consequently, the intersection between cutting region **221** and chamfer **211** (between flats **230***a*, **230***b*) of each cutter element **200** defines a cutting edge **229** of that cutter element **200**. Each cutting edge **229** defines an extension height or the corresponding cutter element **200**. In general, the extension height of a cutter element (e.g., cutter element **200**) is generally the distance from the cutter support surface of the blade to which the cutter element is mounted to the outermost point or portion of the cutter element as measured perpendicular to the cutter supporting surface. The extension heights of cutter elements **200** can be selected to so as to ensure that cutting edges **229** of cutter elements **200** achieve the desired depth of cut, or at least be in contact with the rock during drilling.

During drilling operations, each cutting face **220** engages, penetrates, and shears the formation as the bit **100** is rotated in the cutting direction **106** and is advanced through the formation. Due to the orientation of cutter elements **200**, cutting edges **229** of cutter elements **200** function as the primary cutting edges as cutter elements **200** engage the formation. The sheared formation material slides along cutting region **221** and lateral side regions **223***a*, **223***b* as cutting faces **220** pass through the formation with flats **230***a*, **230***b* and the portion of outer surface **202** therebetween sliding along and bearing against the exposed uncut formation. Thus, as each cutting face **220** advances through the formation, it cuts a kerf in the formation generally defined by the cutting profile of the cutting face **220**. The geometry of cutting face **220** is particularly designed to offer the potential to improving cutting efficiency and cleaning efficiency to increase rate of penetration (ROP) and durability of bit **100**. In particular, the downward slope of regions **221**, **222** toward base **201** moving from central region **225** to outer surface **212** increases relief relative to the corresponding cutting edge **229**, which allows drilling fluid to be directed toward the cutting edge **229** and formation cuttings to efficiently slide along cutting face **220**. The downward slope of lateral side regions **223***a*, **223***b* toward base **201** moving laterally from ridge **227** allows cutting face **220** to draw the extrudates of formation material.

Referring now to FIGS. **6**A-**6**D, another embodiment of a cutter element **300** is shown. In general, a plurality of cutter elements **300** can be used in place of cutter elements **200** on bit **100** previously described.

Cutter element **300** is substantially the same as cutter element **200** previously described with the exception that an additional pair of planar surfaces or flats **230***a*', **230***b*' extend across radially outer surfaces **202**, **212** of substrate **201** and cutting layer **210**, respectively, and two cutting edges **229**, **229**' are provided. More specifically, in this embodiment, insert **300** includes a base **201** and a cutting disc or layer **210** bonded to the base **201** at a plane of intersection **209**. Base **201** and cutting layer **210** are each as previously described. Thus, base **201** has a central axis **205**, a first end **201***a* bonded to cutting layer **210**, a second end **201***b* distal cutting layer **210**, and a radially outer surface **202** extending axially between ends **201***a*, **201***b*. In addition, cutting layer **210** has a first end **210***a* distal substrate **201**, a second end **210***b* bonded to end **201***a* of substrate **201**, and a radially outer surface **212** extending axially between ends **210***a*, **210***b*. The outer surface of cutting layer **210** at first end **210***a* defines the cutting face **220** of cutter element **300**. In this embodiment, a chamfer or bevel **211** is provided at the intersection of cutting face **220** and outer surface **212** about the entire outer periphery of cutting face **220**.

Cutting face **220** includes a central region or surface **225**, a cutting region or surface **221** extending radially from central region **225** to outer surface **212**, a relief region or surface **222** extending radially from central region **225** to outer surface **212**, and a pair of lateral side regions or surfaces **223***a*, **223***b* extending from regions **225**, **221**, **222** to outer surface **212**, each region **221**, **222**, **223***a*, **223***b*, **225** is as previously described. Thus, for example, the ratio of the length L_{225} of central region **225** to the diameter of cutter element **300** is less than 1.0, preferably between 0.10 and 0.90, more preferably between 0.20 and 0.80, and even more preferably between 0.25 and 0.75, and still even more preferably between 0.33 and 0.66; and the aspect ratio of central region **225** is preferably less than 50.0, more preferably between 0.10 and 30.0, more preferably between 0.50 and 30.0, even more preferably between 1.0 and 10.0, and still even more preferably between 1.0 and 5.0. In some embodiments, the aspect ratio of the central region (e.g., central region **225**) is between 0.25 and 10.0. The length L_{225} and width W_{225} of central region **225** of cutter element **300** are determined in the same manner as previously described with respect to cutter element **200**. Further, a pair of planar surfaces or flats **230***a*, **230***b* as previously described extend across radially outer surfaces **202**, **212** of substrate **201** and cutting layer **210**, respectively. However, unlike cutter element **200** previously described, in this embodiment, another pair of planar surfaces or flats **230***a*', **230***b*' extend across radially outer surfaces **202**, **212** of substrate **201** and cutting layer **210**, respectively.

As will be described in more detail below, cutter element **300** is designed and configured such that it includes two cutting edges **229**, **229**' that are used one at a time such that cutter element **300** can engage and shear the formation with one cutting edge **229**, and then when that cutting edge **229** is sufficiently worn, cutter element **300** can be removed from the bit (e.g., bit **100**), rotated, and then reattached to the bit to allow the other unworn cutting edge **229**' to engage and shear the formation. This offer the potential to enhance the overall operating lifetime of cutter element **300** as compared to cutter element **200** previously described that includes one cutting edge **229**. Cutting edge **229** is disposed at the intersection of region **221** and chamfer **211** circumferentially between flats **230***a*, **230***b*, while cutting edge **229**' is disposed at the intersection of region **222** and outer surface **212** circumferentially between flats **230***a*', **230***b*'. When cutting edge **229** is positioned to engage and shear the formation, region **221** functions as a cutting region while region **222** functions as a relief region, whereas when cutting edge **229**' is positioned to engage and shear the formation, region **222** functions as a cutting region while region **221** functions as a relief region. Accordingly, in this embodiment, each region **221**, **222** may be referred to as a “cutting” region or a “relief” region depending on the orientation of cutter element **300** when it is mounted to bit **100**.

Referring still to FIGS. **6**A-**6**E, flats **230***a*', **230***b*' are substantially the same as flats **230***a*, **230***b* previously described, but are generally disposed on the opposite side of ridge **227** as flats **230***a*, **230***b*. In particular, each flat **230***a*', **230***b*' extends axially from cutting face **220** along outer surface **212** of cutting layer **201** and across plane of intersection **209** into and along outer surface **202** of substrate **201**. However, flats **230***a*', **230***b*' do not extend to second end **201***b* of substrate **201**. Rather, flats **230***a*', **230***b*' terminate proximal but axially spaced from end **201***b*. Each flat **230***a*', **230***b*' is contiguous and smooth as it extends across outer surfaces **212**, **202**. In addition, flats **230***a*', **230***b*' are circumferentially spaced along outer surfaces **202**, **212**, and generally positioned on opposite circumferential sides of facet **222**. Flat **230***a*' circumferentially spans a portion of cutting facet **222** and lateral facet **223***a* along outer surface **212** and flat **230***b*' circumferentially spans a portion of cutting facet **222** and lateral facet **223***b*. In this embodiment, each flat **230***a*', **230***b*' is oriented perpendicular to a plane P_{230a}', P_{230b}', respectively, containing the central axis **205**. Planes P_{230a}', P_{230b}' are angularly spaced apart about axis **205** by an angle μ that is less than 180°, preferably 70° to 120°, and more preferably 80° to 100°. In this embodiment, angle μ is 90°. In this embodiment, the angle μ between flats **230***a*, **230***b* is the same as the angle μ between flats **230***a*', **230***b*'. However, in other embodiments, the angle μ between flats **230***a*, **230***b* may be different from the angle μ between flats **230***a*', **230***b*'.

Each flat **230***a*', **230***b*' generally slopes radially outward moving axially from its end at cutting face **220** to its end along substrate **201**. As with flats **230***a*, **230***b* previously described and shown in FIG. **5**F, each flat **230***a*', **230***b*' is oriented at an acute angle σ measured in plane P_{230a}', P_{230b}', respectively, between central axis **205** and flat **230***a*', **230***b*', respectively. Each angle σ is preferably 2° to 10°, and more preferably 6° to 8°. In this embodiment, each angle σ is 7°. Although the angle σ between each flat **230***a*', **230***b*' relative to central axis **205** measured in plane P_{230a}', P_{230b}' respectively, is the same in this embodiment, in other embodiments, the angle the angle σ between each flat **230***a*', **230***b*' relative to central axis **205** measured in plane P_{230a}', P_{230b}', respectively, may be different. Still further, in this embodiment, the angle σ at which each flat **230***a*, **230***b*, **230***a*', **230***b*' is oriented relative to central axis **205** is the same, however, in other embodiments, the angle σ of one or more flat(s) **230***a*, **230***b*, **230***a*', **230***b*' may be different than the others.

As best shown in the top view of cutter element **300** in FIG. **6**B (looking at cutting face **220** as viewed parallel to central axis **205**), in this embodiment, cutting face **220** is symmetric about the reference plane **228** that contains central axis **205**, is disposed between lateral regions **223***a*, **223***b*, and bisects crown **227** and regions **221**, **222**. In this embodiment, planes P_{230a}, P_{230b} are equally angularly spaced from plane **228** (on opposite directions from plane **228**) and planes P_{230a}', P_{230b}' are equally angularly spaced from plane **228** (on opposite directions from plane **228**). Thus, the angle between planes **228**, P_{230a} is ½ the angle μ between planes P_{230a}, P_{230b}, the angle between planes **228**, P_{230b} is ½ the angle μ between planes P_{230a}, P_{230b}, the angle between planes **228**, P_{230a}' is ½ the angle μ between planes P_{230a}', P_{230b}', and the angle between planes **228**, P_{230b}' is ½ the angle μ between planes P_{230a}', P_{230b}'. In other embodiments, planes P_{230a}, P_{230b} may not be equally angularly spaced from plane **228**, and/or planes P_{230a}', P_{230b}' may not be equally angularly spaced from plane **228**.

Cutting elements **300** are mounted in bit body **110** in the same manner and orientation as cutter elements **200** previously described. More specifically, each cutter element **300** is mounted to a corresponding blade **141**, **142** with substrate **201** received and secured in a pocket formed in the cutter support surface **144** of the blade **141**, **142** to which it is fixed by brazing or other suitable means. In addition, each cutter element **300** is oriented with axis **205** oriented generally parallel or tangent to cutting direction **106** and such that the corresponding cutting face **220** is exposed and leads the cutter element **300** relative to cutting direction **106** of bit **100**. Further, cutter elements **300** are oriented with corresponding planes **228** oriented perpendicular to the cutter support surface **144**, one region **221**, **222** distal the corresponding cutter support surface **144** (with one cutting edge **229**, **229**' defining the extension height of the cutter element **300**), and the other region **221**, **222** proximal the corresponding cutter support surface **144**.

During drilling operations, cutting faces **220** of cutter elements **300** engage, penetrate, and shear the formation in the same manner as cutting faces **220** of cutter elements **200** previously described. However, since cutting faces **220** of cutter elements **300** include two cutting edges **229**, **229**', one cutting edge **229**, **229**' of each cutter element **300** can be used first to engage, penetrate, and shear the formation, and then when those cutting edges **229**, **229**' are sufficiently worn (e.g., the cutting efficiency and rate of penetration of the bit are sufficiently low), cutter elements **300** can be removed from the bit body **110**, and then re-mounted to bit body **110** with the other cutting edge **229**, **229**' positioned to engage, penetrate and shear the formation. The ability to reuse cutter elements **300** after one cutting edge **229**, **229**' is sufficiently worn offers the potential to significantly increase the operating lifetime of cutter elements **300** as compared to other cutter elements that include only one primary cutting edge.

In the embodiments of cutter elements **200**, **300** previously described and shown in FIGS. **5**A-**5**F and **6**A-**6**D, respectively, ridge **227** was generally convex or bowed outwardly in front side view (FIGS. **5**C and **6**C) and in lateral side view (FIGS. **5**D and **6**D), both cutting region **221** and relief region **222** sloped upward and axially away from base **201** moving radially inward toward center region **225**, each discrete region **221**, **222**, **225**, **223***a*, **223***b* on cutting face **220** was planar, and each discrete region **221**, **222**, **225**, **223***a*, **223***b* intersected each adjacent region **221**, **222**, **225**, **223***a*, **223***b* along a linear edge **224***a*, **224***b*, **224***c*, **224***d*, **226***a*, **226***b*, **226***c*, **226***d*. However, in other embodiments, the ridge (e.g., ridge **227**) may be generally concave or generally partly concave and partly convex in lateral side view; one or both of the cutting region and the relief region (e.g., regions **221**, **222**) may slope downward and axially toward the base (e.g., **201**) moving radially toward the center region (e.g., region **225**); one or more of the center region (e.g., region **225**), the cutting region (e.g., region **221**), and the relief region (e.g., region **222**) may be continuously and smoothly curved (e.g., concave or convex); and some discrete regions (e.g., discrete regions **221**, **222**, **225**, **223***a*, **223***b*) on the cutting face (e.g., cutting face **220**) may intersect an adjacent region on the cutting face along a non-linear edge. Exemplary embodiments of cutter elements including such variations will now be described and shown in FIGS. **7**A-**7**E, **8**A-**8**E, and **9**A-**9**E.

Referring now to FIGS. **7**A-**7**E, an embodiment of a cutter element **400** is shown. In general, a plurality of cutter elements **400** can be used in place of cutter elements **200** on bit **100** previously described. Cutter element **400** is substantially the same as cutter element **200** previously described with the exception that the cutting region (e.g, cutting region **221**) and the relief region (e.g., relief region **222**) of the cutting face (e.g., cutting face **220**) are smoothly curved and concave. More specifically, in this embodiment, cutter element **400** includes a base **201** and a cutting disc or layer **410** bonded to the base **201** at a plane of intersection **209**. Base **201** is as previously described. Thus, base **201** has a central axis **205**, a first end **201***a* bonded to cutting layer **410**, a second end **201***b* distal cutting layer **410**, and a radially outer surface **202** extending axially between ends **201***a*, **201***b*.

Cutting layer **410** is substantially the same as cutting layer **210** previously described except that the cutting region (e.g., cutting region **221**) and the relief region (e.g., relief region **222**) of the cutting face (e.g., cutting face **220**) are not planar. In particular, cutting layer **410** has a first end **410***a* distal substrate **201**, a second end **410***b* bonded to end **201***a* of substrate **201**, and a cylindrical radially outer surface **412** extending axially between ends **410***a*, **410***b*. The outer surface of cutting layer **410** at first end **410***a* defines the cutting face **420** of cutter element **400**. In this embodiment, a chamfer or bevel **411** is provided at the intersection of cutting face **420** and outer surface **412** about the entire outer periphery of cutting face **420**.

Cutting face **420** is defined by a plurality of discrete regions or surfaces. More specifically, cutting face **420** includes a rectangular central region or surface **225**, a cutting region or surface **421** extending radially from central region **225** to outer surface **412**, a relief region or surface **422** extending radially from central region **225** to outer surface **412**, and a pair of lateral side regions or surfaces **223***a*, **223***b* extending from regions **225**, **421**, **422** to outer surface **412**. Regions **421**, **422**, **223***a*, **223***b* are circumferentially disposed about axis **205** and central region **225**. In addition, regions **421**, **422**, **223***a*, **223***b* are positioned circumferentially adjacent each other with each region **421**, **422** circumferentially disposed between regions **223***a*, **223***b* and each region **223***a*, **223***b* circumferentially disposed between regions **421**, **422**. The centerlines of regions **421**, **422** are angularly spaced 180° apart about axis **205**. Accordingly, regions **421**, **422** extend radially in opposite directions from central region **225** to outer surface **412**. Each region **225**, **223***a*, **223***b* is as previously described. Namely, region **225** is planar, centered relative to axis **205**, and oriented perpendicular to axis **205**, and regions **223***a*, **223***b* are planar, slope axially downward toward base **201** moving radially outward from regions **225**, **421**, **422** to outer surface **412**, and are oriented at the non-zero acute angle α measured from the lateral region **223***a*, **223***b* to a reference plane oriented perpendicular to central axis **205** in the front side view and the rear side view as previously described. In addition, the ratio of the length L_{225} of central region **225** to the diameter of cutter element **400** is less than 1.0, preferably between 0.10 and 0.90, more preferably between 0.20 and 0.80, and even more preferably between 0.25 and 0.75, and still even more preferably between 0.33 and 0.66; and the aspect ratio of central region **225** is preferably less than 50.0, more preferably between 0.10 and 30.0, more preferably between 0.50 and 30.0, even more preferably between 1.0 and 10.0, and still even more preferably between 1.0 and 5.0. In some embodiments, the aspect ratio of the central region (e.g., central region **225**) is between 0.25 and 10.0. The length L_{225} and width W_{225} of central region **225** of cutter element **400** are determined in the same manner as previously described with respect to cutter element **200**. However, unlike cutting region **221** and relief region **222** of cutting face **220** of cutter element **200** previously described, in this embodiment, cutting region **421** is smoothly and continuously curved and concave and relief region **422** is smoothly and continuously curved and concave. Thus, cutting region **421** curves axially upward and away from base **201** moving radially from center region **225** to outer surface **412**, and relief region **422** curves axially upward and away from base **201** moving from center region **225** to outer surface **412**. As a result, and described in more detail below, an elongate ridge **427** defined by regions **421**, **225**, **422** is generally concave in lateral side view (FIG. **7**D), and the lateral side regions **223***a*, **223***b* intersect cutting region **421** and relief region **422** along non-linear edges **424***a*, **424***b*, **424***c*, **424***d*. In this embodiment, both regions **421**, **422** smoothly transition and blend into center region **225**.

In this embodiment, each region **421**, **422** is a cylindrical surface disposed at a corresponding radius of curvature. As best shown in FIG. **7**D, each region **421**, **422** is a cylindrical surface disposed at a radius R_{421}, R_{422}, respectively, relative to a corresponding axis oriented perpendicular to a reference plane **428** that contains central axis **205**, is disposed between lateral regions **223***a*, **223***b*, and bisects crown **427** and regions **421**, **422** Each radius R_{421}, R_{422} ranges from 15.0 to 100.0 mm, and more preferably ranges from 20.0 to 80.0 mm. In general, radii radius R_{421}, R_{422} can be the same or different. In this embodiment, each radius R_{421}, R_{422} is the same, and in particular, each radius R_{421}, R_{422} is 30.0 mm.

As previously described, lateral regions **223***a*, **223***b* slope axially downward toward substrate **201** moving from regions **421**, **225**, **422** to outer surface **412**. As a result, regions **421**, **225**, **422** define an elongate, generally raised ridge or crown **427** extending linearly completely across cutting face **420**. Thus, ridge **427** may be described as having a first end at outer surface **412** at one side of cutter element **400** and a second end at outer surface **412** at the radially opposite side of cutter element **400**. Ridge **427** (or at least a portion thereof) defines the maximum height of cutter element **400** measured axially from end **201***b* to cutting face **420** at end **410***a*.

Due to the geometry of regions **223***a*, **223***b*, **225**, **421**, **422**, and unlike crown **227** previously described, crown **427** is generally convex in front side view (FIG. **7**C) but generally concave in lateral side view (FIG. **7**D). In addition, due to the geometry of regions **225**, **223***a*, **223***b*, region **225** intersects regions **223***a*, **223***b* along linear edges **226***b*, **226***d*, while regions **421**, **422** intersect lateral regions **223***a*, **223***b* along curved edges **424***a*, **424***b*, **424***c*, **424***d*. Curved regions **421**, **422** smoothly transition into planar central region **225**, and thus, there is not a distinct edge between regions **421**, **225** or regions **422**, **225** in this embodiment. However, for purposes of clarity, the transitions from planar central region **225** into smoothly curved convex regions **421**, **422** are identified with dashed lines **426***a*, **426***c*, respectively. Since dashed lines **426***a*, **426***c* define the locations at which the slope of crown **427** changes moving from central region **425** into curved regions **421**, **422**, lines **426***a*, **426***c* may also be referred to as transition lines. For purposes of clarity, the length L_{225} of central region **225** of crown **427** is measured parallel to plane **428** from line **426***a* to line **426***b*.

As best shown in the top view of cutter element **400** in FIG. **7**B (looking at cutting face **420** as viewed parallel to central axis **205**), in this embodiment, curved edges **424***a*, **424***d* generally move toward each other moving radially along cutting region **421** from central region **225** to outer surface **412**, and curved edges **424***b*, **424***c* generally move toward each other moving radially along relief region **222** from central region **225** to outer surface **412**. As a result, and unlike cutter element **200** previously described, cutting region **421** has a width measured perpendicular to a reference plane **428** containing central axis **205** in top view that decreases moving radially from central region **225** to outer surface **412**, and similarly, relief region **422** has a width measured perpendicular to reference plane **428** in top view that decreases moving radially from central region **225** to outer surface **412**.

Referring still to FIGS. **7**A-**7**E, a pair of planar surfaces or flats **230***a*, **230***b* extend across radially outer surfaces **202**, **412** of substrate **201** and cutting layer **410**, respectively. Flats **230***a*, **230***b* are as previously described. For example, flats **230***a*, **230***b* are circumferentially spaced along outer surfaces **202**, **412**, and generally positioned on opposite circumferential sides of cutting region **421**. Flat **230***a* circumferentially spans a portion of cutting region **421** and lateral facet **223***a* along outer surface **412** and flat **230***b* circumferentially spans a portion of cutting region **421** and lateral facet **223***b* along outer surface **412**. In addition, in this embodiment, each flat **230***a*, **230***b* is oriented perpendicular to a plane P_{230a}, P_{230b}, respectively, containing the central axis **205** Planes P_{230a}, P_{230b} are angularly spaced apart about axis **205** by an angle μ that is less than 180°, preferably 70° to 120°, and more preferably 80° to 100°. In this embodiment, angle μ is 90°. Further, each flat **230***a*, **230***b* generally slopes radially outward moving axially from its end at cutting face **420** to its end along substrate **201**. More specifically, in this embodiment, each flat **230***a*, **230***b* is oriented at an acute angle σ measured in plane P_{230a} between central axis **205** and flat **230***a*. Angle σ is preferably 2° to 10°, and more preferably 6° to 8°. In this embodiment, angle σ is 7°.

As best shown in the top view of cutter element **400** in FIG. **7**B (looking at cutting face **420** as viewed parallel to central axis **205**), in this embodiment, cutting face **420** is symmetric about the reference plane **428** that contains central axis **205**, is disposed between lateral regions **223***a*, **223***b*, and bisects crown **427** and regions **421**, **422**. A cutting edge **429** is defined at the intersection of cutting region **421** and chamfer **411** between flats **230***a*, **230***b*.

A plurality of cutting elements **400** are mounted in bit body **110** in the same manner and orientation as cutter elements **200** previously described. More specifically, each cutter element **400** is mounted to a corresponding blade **141**, **142** with substrate **201** received and secured in a pocket formed in the cutter support surface **144** of the blade **141**, **142** to which it is fixed by brazing or other suitable means. In addition, each cutter element **400** is oriented with axis **205** oriented generally parallel or tangent to cutting direction **106** and such that the corresponding cutting face **420** is exposed and leads the cutter element **400** relative to cutting direction **106** of bit **100**. Further, cutter elements **400** are oriented with corresponding planes **428** oriented perpendicular to the cutter support surface **144**, cutting region **421** distal the corresponding cutter support surface **144** (with cutting edge **429** defining the extension height of the cutter element **400**), and relief region **421** proximal the corresponding cutter support surface **144**. During drilling operations, cutting faces **420** of cutter elements **400** engage, penetrate, and shear the formation in the same manner as cutting faces **220** of cutter elements **200** previously described.

In the embodiment of cutter element **200** described above and shown in FIGS. **5**A-**5**F, regions **221**, **222**, **225** are planar; and in the embodiment of cutter element **400** described above and shown in FIGS. **7**A-**7**E, regions **421**, **422** are smoothly curved and concave, while central region **225** is planar. However, in other embodiments, the cutting region (e.g., cutting region **221**, **421**) may be smoothly curved and convex, the relief region (e.g., relief region **222**, **422**) may be smoothly curved and convex, the central region (e.g., central region **225**) may be smoothly curved (concave or convex), or combinations thereof.

Referring now to FIGS. **8**A-**8**E, an embodiment of a cutter element **500** is shown. In general, a plurality of cutter elements **500** can be used in place of cutter elements **200** on bit **100** previously described. Cutter element **500** is substantially the same as cutter element **200** previously described with the exception that the central region (e.g., central region **225**) of the cutting face (e.g., cutting face **220**) is smoothly curved and concave. More specifically, in this embodiment, cutter element **500** includes a base **201** and a cutting disc or layer **510** bonded to the base **201** at a plane of intersection **209**. Base **201** is as previously described. Thus, base **201** has a central axis **205**, a first end **201***a* bonded to cutting layer **510**, a second end **201***b* distal cutting layer **510**, and a radially outer surface **202** extending axially between ends **201***a*, **201***b*.

Cutting layer **510** is substantially the same as cutting layer **210** previously described except that both planar cutting regions **221**, **222** slope upward and axially away from base **201** moving radially outward and the central region (e.g., central region **225**) is not planar. In particular, cutting layer **510** has a first end **510***a* distal substrate **201**, a second end **510***b* bonded to end **201***a* of substrate **201**, and a cylindrical radially outer surface **512** extending axially between ends **510***a*, **510***b*. The outer surface of cutting layer **510** at first end **510***a* defines the cutting face **520** of cutter element **500**. In this embodiment, a chamfer or bevel **511** is provided at the intersection of cutting face **520** and outer surface **512** about the entire outer periphery of cutting face **520**.

Cutting face **520** is defined by a plurality of discrete regions or surfaces. More specifically, cutting face **520** includes a generally rectangular central region or surface **525**, a cutting region or surface **221** extending radially from central region **525** to outer surface **512**, a relief region or surface **222** extending radially from central region **525** to outer surface **512**, and a pair of lateral side regions or surfaces **223***a*, **223***b* extending from regions **525**, **221**, **222** to outer surface **512**. Regions **221**, **222**, **223***a*, **223***b* are circumferentially disposed about axis **205** and central region **525**. In addition, regions **221**, **222**, **223***a*, **223***b* are positioned circumferentially adjacent each other with each region **221**, **222** circumferentially disposed between regions **223***a*, **223***b* and each region **223***a*, **223***b* circumferentially disposed between regions **221**, **222**. The centerlines of regions **221**, **222** are angularly spaced 180° apart about axis **205**. Accordingly, regions **221**, **222** extend radially in opposite directions from central region **525** to outer surface **512**. Each region **221**, **222**, **223***a*, **223***b* is as previously described except that regions **221**, **222** slope upward and axially away from base **201** moving radially outward from central region **525** to outer surface **512**. Namely, each region **221**, **222** is planar and oriented at non-zero acute angle β, θ, respectively, measured from region **221**, **222**, respectively, to a reference plane oriented perpendicular to central axis **205** in the lateral side view. Each angle β, θ is less than 45°, preferably ranges from 1° to 20°, and more preferably ranges from 2° to 10°. In this embodiment, angle β is 6° and angle θ is 6°. In general, angles β, θ can be the same or different. In addition, regions **223***a*, **223***b* are planar, slope axially downward toward base **201** moving radially outward from regions **525**, **221**, **222** to outer surface **512**, and are oriented at the non-zero acute angle α measured from the lateral region **223***a*, **223***b* to a reference plane oriented perpendicular to central axis **205** in the front side view and the rear side view as previously described. However, unlike central region **225** of cutting face **220** of cutter element **200** previously described, in this embodiment, central region **525** is smoothly curved and concave. Thus, central region **525** curves axially upward and away from base **201** moving radially from axis **205** to cutting region **221** and curves axially upward and away from base **201** moving radially from axis **205** to relief region **222**. As a result of the slope of regions **221**, **222** and the concave geometry of central region **525**, and described in more detail below, an elongate ridge **527** defined by regions **221**, **525**, **222** is generally concave in lateral side view (FIG. **8**D), and the lateral side regions **223***a*, **223***b* intersect cutting central region **525** along non-linear edges **526***b*, **526***d*, respectively. In this embodiment, a plane tangent to central region **525** at the intersection of axis **205** and region **525** is oriented perpendicular to axis **205**. Central region **525** smoothly transitions and blends into regions **221**, **222**.

In this embodiment, central region **525** is a cylindrical surface disposed at a radius of curvature. As best shown in FIG. **8**D, region **525** is a cylindrical surface disposed at a radius R_{525} relative to an axis oriented perpendicular to a reference plane **528** that contains central axis **205**, is disposed between lateral regions **223***a*, **223***b*, and bisects crown **527** and regions **221**, **222**. Radius R_{525} ranges from 1.0 to 50.0 mm, and more preferably ranges from 5.0 to 20.0 mm. In this embodiment, radius R_{525} is 27 mm.

As previously described, lateral regions **223***a*, **223***b* slope axially downward toward substrate **201** moving from regions **221**, **525**, **222** to outer surface **512**. As a result, regions **221**, **525**, **222** define an elongate, generally raised ridge or crown **527** extending linearly completely across cutting face **520**. Thus, ridge **527** may be described as having a first end at outer surface **512** at one side of cutter element **500** and a second end at outer surface **512** at the radially opposite side of cutter element **500**. Ridge **527** (or at least a portion thereof) defines the maximum height of cutter element **500** measured axially from end **201***b* to cutting face **520** at end **510***a*.

Due to the geometry of regions **223***a*, **223***b*, **525**, **221**, **222**, crown **527** is generally convex in front side view (FIG. **8**C) but generally concave in lateral side view (FIG. **8**D). In addition, due to the geometry of regions **525**, **223***a*, **223***b*, region **525** intersects regions **223***a*, **223***b* along non-linear edges **526***b*, **526***d*, while regions **221**, **222** intersect lateral regions **223***a*, **223***b* along linear edges **224***a*, **224***b*, **224***c*, **224***d*. Planar regions **221**, **222** smoothly transition into concave central region **525**, and thus, there is not a distinct edge between regions **221**, **525** or regions **222**, **525** in this embodiment. However, for purposes of clarity, the transitions from central region **525** into planar regions **221**, **222** are identified with dashed lines **526***a*, **526***c*, respectively. Since dashed lines **526***a*, **526***c* define the locations at which the slope of crown **527** changes moving from concave central region **525** into planar regions **221**, **222**, lines **526***a*, **526***c* may also be referred to as transition lines. For purposes of clarity, the length L_{525} of central region **225** of crown **527** is measured parallel to plane **528** from line **526***a* to line **526***b*.

As best shown in the top view of cutter element **500** in FIG. **8**B (looking at cutting face **520** as viewed parallel to central axis **205**), in this embodiment, linear edges **224***a*, **224***d* generally slope toward each other moving radially along cutting region **221** from central region **525** to outer surface **512**, and linear edges **224***b*, **224***c* generally move toward each other moving radially along relief region **222** from central region **525** to outer surface **512**. As a result, and unlike cutter element **200** previously described, cutting region **221** has a width measured perpendicular to a reference plane **528** containing central axis **205** in top view that decreases moving radially from central region **525** to outer surface **512**, and similarly, relief region **222** has a width measured perpendicular to reference plane **528** in top view that decreases moving radially from central region **525** to outer surface **512**.

As best shown in FIG. **8**B, central region **525** has a length L_{525} measured parallel to plane **528** from transition line **526***a* to transition line **526***c* in top view, and a width W_{525} measured perpendicular to plane **528** from edge **526***b* to edge **526***d* in top view. As previously described, the geometry of the central region of the cutting face (e.g., central region **525** of cutting face **520**) can be characterized by the ratio of the length of the central region (e.g., length L_{525}) to the diameter of the corresponding cutter element and the aspect ratio of the central region (e.g., the ratio of the length L_{525} to the width W_{525}). Thus, in this embodiment, the geometry of central region **525** may be characterized by the ratio of the length L_{525} to the diameter of cutter element **500** and the aspect ratio equal to the ratio of the length L_{525} to the width W_{525}. Similar to embodiments of central region **225** previously described, in this embodiment, the ratio of the length L_{525} to the diameter of cutter element **500** is less than 1.0, preferably between 0.10 and 0.90, more preferably between 0.20 and 0.80, and even more preferably between 0.25 and 0.75, and still even more preferably between 0.33 and 0.66; and the aspect ratio of central region **525** is preferably less than 50.0, more preferably between 0.10 and 30.0, more preferably between 0.50 and 30.0, even more preferably between 1.0 and 10.0, and still even more preferably between 1.0 and 5.0. In some embodiments, the aspect ratio of the central region (e.g., central region **525**) is between 0.25 and 10.0.

It should be appreciated that unlike previous embodiments in which the central region is rectangular (e.g., central region **225**) with the length being measured between parallel linear edges (e.g., between parallel linear edges **226***a*, **226***c*) and the width being measured between parallel linear edges (e.g., between parallel linear edges **226***b*, **226***d*), in this embodiment, the length L_{525} is measured between parallel linear edges **526***a*, **526***c* but the width W_{525} is measured between non-parallel, non-linear transition lines **526***b*, **526***d*. Consequently, the length L_{525} is constant at all points along edges **526***a*, **526***c*, whereas the width W_{525} varies depending on where it is measured along edges **526***b*, **526***d*. For purposes of clarity, in embodiments where the length of the central region (e.g., the length L_{525}) and/or the width of the central region (e.g., the width W_{525}) varies depending on where it is measured, the maximum length of the central region and the maximum width of the central region are used to determine the ratio of the length of the central region to the diameter of the corresponding cutter element and the aspect ratio.

Referring still to FIGS. **8**A-**8**E, a pair of planar surfaces or flats **230***a*, **230***b* extend across radially outer surfaces **202**, **512** of substrate **201** and cutting layer **510**, respectively. Flats **230***a*, **230***b* are as previously described. For example, flats **230***a*, **230***b* are circumferentially spaced along outer surfaces **202**, **512**, and generally positioned on opposite circumferential sides of cutting region **221**. Flat **230***a* circumferentially spans a portion of cutting region **221** and lateral facet **223***a* along outer surface **512** and flat **230***b* circumferentially spans a portion of cutting region **221** and lateral facet **223***b* along outer surface **512**. In addition, in this embodiment, each flat **230***a*, **230***b* is oriented perpendicular to a plane P_{230a}, P_{230b}, respectively, containing the central axis **205**. Planes P_{230a}, P_{230b} are angularly spaced apart about axis **205** by an angle μ that is less than 180°, preferably 70° to 120°, and more preferably 80° to 100°. In this embodiment, angle μ is 90°. Further, each flat **230***a*, **230***b* generally slopes radially outward moving axially from its end at cutting face **420** to its end along substrate **201**. More specifically, in this embodiment, each flat **230***a*, **230***b* is oriented at an acute angle σ measured in plane P_{230a} between central axis **205** and flat **230***a*. Angle σ is preferably 2° to 10°, and more preferably 6° to 8°. In this embodiment, angle σ is 7°.

As best shown in the top view of cutter element **500** in FIG. **8**B (looking at cutting face **520** as viewed parallel to central axis **205**), in this embodiment, cutting face **520** is symmetric about the reference plane **528** that contains central axis **205**, is disposed between lateral regions **223***a*, **223***b*, and bisects crown **527** and regions **221**, **222**. A cutting edge **529** is defined at the intersection of cutting region **221** and chamfer **511** between flats **230***a*, **230***b*.

A plurality of cutting elements **500** are mounted in bit body **110** in the same manner and orientation as cutter elements **200** previously described. More specifically, each cutter element **500** is mounted to a corresponding blade **141**, **142** with substrate **201** received and secured in a pocket formed in the cutter support surface **144** of the blade **141**, **142** to which it is fixed by brazing or other suitable means. In addition, each cutter element **500** is oriented with axis **205** oriented generally parallel or tangent to cutting direction **106** and such that the corresponding cutting face **520** is exposed and leads the cutter element **500** relative to cutting direction **106** of bit **100**. Further, cutter elements **500** are oriented with corresponding planes **528** oriented perpendicular to the cutter support surface **144**, cutting region **221** distal the corresponding cutter support surface **144** (with cutting edge **529** defining the extension height of the cutter element **500**), and relief region **221** proximal the corresponding cutter support surface **144**. During drilling operations, cutting faces **520** of cutter elements **500** engage, penetrate, and shear the formation in the same manner as cutting faces **220** of cutter elements **200** previously described.

In the embodiment of cutter element **200** described above and shown in FIGS. **5**A-**5**F, both planar regions **221**, **222** slope downward and axially toward base **201** moving radially from central region **225** to outer surface **212**, and the widths of regions **221**, **222** increase moving radially from central region **225** to outer surface **212** in top view (FIG. **5**B); and in the embodiment of cutter element **500** described above and shown in FIGS. **8**A-**8**E, both planar regions **221**, **222** slope upward and axially away from base **201** moving radially from central region **525** to outer surface **512**, and the widths of regions **221**, **222** decrease moving radially from central region **525** to outer surface **512** in top view (FIG. **8**B). However, in other embodiments, the planar cutting region (e.g., cutting region **221**) and the planar relief region (e.g., relief region **222**) may slope in opposite directions, and further, the cutting region and the relief region may have widths that increase and decrease, respectively, or vice versa.

Referring now to FIGS. **9**A-**9**E, an embodiment of a cutter element **600** is shown. In general, a plurality of cutter elements **600** can be used in place of cutter elements **200** on bit **100** previously described. Cutter element **600** is the same as cutter element **200** previously described with the exception that cutting region **221** and relief region **222** slope in opposite directions, and the width of cutting region **221** measured perpendicular to reference plane **228** in top view (FIG. **9**B) decreases moving radially from central region **225** to outer surface **212**.

In this embodiment, planar cutting region **221** slopes upward and axially away from base **201** moving radially outward from central region **225** to outer surface **212** while planar relief region **222** slopes downward and axially toward base **201** moving radially outward from central region **225** to outer surface **212**. As a result, cutter element **600** has a raise ridge or crown **627** including a portion defined by regions **221**, **225** that is generally convex in lateral side view (FIG. **8**D) and another portion defined by regions **222**, **225** that is generally concave in lateral side view. Ridge **627** extends linearly completely across cutting face **220**. Thus, ridge **627** may be described as having a first end at outer surface **212** at one side of cutter element **600** and a second end at outer surface **212** at the radially opposite side of cutter element **600**. Ridge **627** (or at least a portion thereof) defines the maximum height of cutter element **600** measured axially from end **201***b* to cutting face **220** at end **210***a*.

Each region **221**, **222** is oriented at non-zero acute angle β, θ, respectively, measured from region **221**, **222**, respectively, to a reference plane oriented perpendicular to central axis **205** in the lateral side view (FIG. **8**D). Each angle β, θ is less than 45°, preferably ranges from 1° to 20°, and more preferably ranges from 2° to 10°. In this embodiment, angle β is 5° and angle θ is 5°. Otherwise, cutter element **600** is the same as cutter element **200** previously described.

Central region **225** is as previously described, and thus, the ratio of the length L_{225} of central region **225** to the diameter of cutter element **600** is less than 1.0, preferably between 0.10 and 0.90, more preferably between 0.20 and 0.80, and even more preferably between 0.25 and 0.75, and still even more preferably between 0.33 and 0.66; and the aspect ratio of central region **225** is preferably less than 50.0, more preferably between 0.10 and 30.0, more preferably between 0.50 and 30.0, even more preferably between 1.0 and 10.0, and still even more preferably between 1.0 and 5.0. In some embodiments, the aspect ratio of the central region (e.g., central region **525**) is between 0.25 and 10.0. The length L_{225} and width W_{225} of central region **225** of cutter element **600** are determined in the same manner as previously described with respect to cutter element **200**.

A plurality of cutting elements **600** are mounted in bit body **110** in the same manner and orientation as cutter elements **200** previously described. More specifically, each cutter element **600** is mounted to a corresponding blade **141**, **142** with substrate **201** received and secured in a pocket formed in the cutter support surface **144** of the blade **141**, **142** to which it is fixed by brazing or other suitable means. In addition, each cutter element **600** is oriented with axis **205** oriented generally parallel or tangent to cutting direction **106** and such that the corresponding cutting face **220** is exposed and leads the cutter element **600** relative to cutting direction **106** of bit **100**. Further, cutter elements **600** are oriented with corresponding planes **228** oriented perpendicular to the cutter support surface **144**, cutting region **221** distal the corresponding cutter support surface **144** (with cutting edge **229** defining the extension height of the cutter element **600**), and relief region **221** proximal the corresponding cutter support surface **144**. During drilling operations, cutting faces **220** of cutter elements **600** engage, penetrate, and shear the formation in the same manner as cutting faces **220** of cutter elements **200** previously described.

In the embodiments of cutter elements **200**, **400**, **500**, **600** described above, a pair of planar surfaces or flats **230***a*, **230***b* extend across the radially outer surface **202** of substrate **201** and the radially outer surface **212**, **412**, **512** of the corresponding cutting layer **210**, **410**, **510**. In addition, in the embodiment of cutter element **300** described above, two pair of planar surfaces or flats **230***a*, **230***b*, **230***a*', **230***b*' extend across the radially outer surfaces **202**, **212** of substrate **201** and cutting layer **212**, respectively. In general, embodiments of cutter elements described herein can include two or four flats (e.g., flats **230***a*, **230***b*, **230***a*', **230***b*'). Still further, in some embodiments, no flats are provided.

Referring now to FIGS. **10**A-**10**D, an embodiment of a cutter element **700** is shown. In general, a plurality of cutter elements **700** can be used in place of cutter elements **200** on bit **100** previously described. Cutter element **700** is the same as cutter element **200** previously described with the exception that flats **230***a*, **230***b* have been eliminated. In other words, in this embodiment, no planar flats are provided. Otherwise, cutter element **700** is the same as cutter element **200** previously described.

A plurality of cutting elements **700** are mounted in bit body **110** in the same manner and orientation as cutter elements **200** previously described. More specifically, each cutter element **700** is mounted to a corresponding blade **141**, **142** with substrate **201** received and secured in a pocket formed in the cutter support surface **144** of the blade **141**, **142** to which it is fixed by brazing or other suitable means. In addition, each cutter element **700** is oriented with axis **205** oriented generally parallel or tangent to cutting direction **106** and such that the corresponding cutting face **220** is exposed and leads the cutter element **700** relative to cutting direction **106** of bit **100**. Further, cutter elements **700** are oriented with corresponding planes **228** oriented perpendicular to the cutter support surface **144**, cutting region **221** distal the corresponding cutter support surface **144** (with cutting edge **229** defining the extension height of the cutter element **600**), and relief region **221** proximal the corresponding cutter support surface **144**. During drilling operations, cutting faces **220** of cutter elements **700** engage, penetrate, and shear the formation in the same manner as cutting faces **220** of cutter elements **200** previously described.

Referring now to FIGS. **11A-11D**, an embodiment of a cutter element **800** is shown. In general, a plurality of cutter elements **800** can be used in place of cutter elements **200** on bit **100** previously described. Cutter element **800** is substantially the same as cutter element **500** previously described with the exception that the central region (e.g., central region **525**) of the cutting face (e.g., cutting face **520**) is planar and flats **230***a*, **230***b* have been eliminated. More specifically, in this embodiment, cutter element **800** includes a base **201** and a cutting disc or layer **810** bonded to the base **201** at a plane of intersection **209**. Base **201** is as previously described with the sole exception that no flats (e.g., flats **230***a*, **230***b*) are provided. Thus, base **201** has a central axis **205**, a first end **201***a* bonded to cutting layer **810**, a second end **201***b* distal cutting layer **810**, and a radially outer surface **202** extending axially between ends **201***a*, **201***b*. As no flats are provided, outer surface **202** is a cylindrical surface extending about the entire circumference of base **201**.

Cutting layer **810** is substantially the same as cutting layer **510** previously described. In particular, cutting layer **810** has a first end **810***a* distal substrate **201**, a second end **810***b* bonded to end **201***a* of substrate **201**, and a cylindrical radially outer surface **812** extending axially between ends **810***a*, **810***b*. The outer surface of cutting layer **810** at first end **810***a* defines the cutting face **820** of cutter element **800**. In this embodiment, a chamfer or bevel **811** is provided at the intersection of cutting face **820** and outer surface **812** about the entire outer periphery of cutting face **820**.

Cutting face **820** is defined by a plurality of discrete regions or surfaces. More specifically, cutting face **820** includes a generally rectangular central region or surface **825**, a cutting region or surface **221** extending radially from central region **825** to outer surface **812**, a relief region or surface **222** extending radially from central region **825** to outer surface **812**, and a pair of lateral side regions or surfaces **223***a*, **223***b* extending from regions **825**, **221**, **222** to outer surface **812**. Each region **223***a*, **223***b* is as previously described, and each region **221**, **222** is as previously with respect to cutter element **500**. In particular, regions **221**, **222**, **223***a*, **223***b* are circumferentially disposed about axis **205** and central region **825**. In addition, regions **221**, **222**, **223***a*, **223***b* are positioned circumferentially adjacent each other with each region **221**, **222** circumferentially disposed between regions **223***a*, **223***b* and each region **223***a*, **223***b* circumferentially disposed between regions **221**, **222**. The centerlines of regions **221**, **222** are angularly spaced 180° apart about axis **205**. Accordingly, regions **221**, **222** extend radially in opposite directions from central region **825** to outer surface **812**. Regions **221**, **222** slope upward and axially away from base **201** moving radially outward from central region **825** to outer surface **812**. In addition, each region **221**, **222** is planar and oriented at non-zero acute angle β, θ, respectively, measured from region **221**, **222**, respectively, to a reference plane oriented perpendicular to central axis **205** in the lateral side view. As previously described, each angle β, θ is less than 45°, preferably ranges from 1° to 20°, and more preferably ranges from 2° to 10°. Regions **223***a*, **223***b* are planar, slope axially downward toward base **201** moving radially outward from regions **825**, **221**, **222** to outer surface **812**, and are oriented at the non-zero acute angle α measured from the lateral region **223***a*, **223***b* to a reference plane oriented perpendicular to central axis **205** in the front side view and the rear side view.

Unlike central region **525** of cutting face **520** of cutter element **500** previously described, in this embodiment, central region **825** is planar, and more specifically, is disposed in a plane oriented perpendicular to axis **205**. As a result of the slope of regions **221**, **222** and the planar geometry of central region **825**, and described in more detail below, an elongate ridge **827** defined by regions **221**, **825**, **222** is generally concave in lateral side view (FIG. **11**D).

As previously described, lateral regions **223***a*, **223***b* slope axially downward toward substrate **201** moving from regions **221**, **825**, **222** to outer surface **812**. As a result, regions **221**, **825**, **222** define an elongate, generally raised ridge or crown **827** extending linearly completely across cutting face **820**. Thus, ridge **827** may be described as having a first end at outer surface **812** at one side of cutter element **800** and a second end at outer surface **812** at the radially opposite side of cutter element **800**. Ridge **827** (or at least a portion thereof) defines the maximum height of cutter element **800** measured axially from end **201***b* to cutting face **820** at end **810***a*.

Due to the geometry of regions **223***a*, **223***b*, **825**, **221**, **222**, crown **827** is generally convex in front side view (FIG. **11**C) but generally concave in lateral side view (FIG. **11**D). In addition, region **825** intersects regions **223***a*, **223***b* along non-linear edges **826***b*, **826***d*, respectively, and regions **221**, **222** intersect lateral regions **223***a*, **223***b* along linear edges **224***a*, **224***b*, **224***c*, **224***d*. Since central region **825** and regions **221**, **222** are planar, a distinct, linear edge **826***a*, **826***c* is defined at the intersection of central region **825** and each region **221**, **222**, respectively.

As best shown in FIG. **11**B, central region **825** has a length L_{825} measured parallel to plane **828** from edge **826***a* to edge **826***c* in top view, and a width W_{825} measured perpendicular to plane **828** from edge **826***b* to edge **826***d* in top view. In this embodiment, linear edges **826***a*, **826***c* are oriented parallel to each other while non-linear edges **826***b*, **826***d* are not oriented parallel to each other. Thus, the length L_{825} measured between edges **826***a*, **826***c* is constant at all points along edges **826***a*, **826***c*, while the width W_{825} varies depending on where it is measured along edges **826***b*, **826***d*. The geometry of central region **825** may be characterized by the ratio of the length L_{825} to the diameter of cutter element **800** and an "aspect ratio" that is equal to the ratio of the length L_{825} to the width W_{825}. The ratio of the length L_{825} to the diameter of cutter element **800** is less than 1.0, preferably between 0.10 and 0.90, more preferably between 0.20 and 0.80, and even more preferably between 0.25 and 0.75, and still even more preferably between 0.33 and 0.66; and the aspect ratio of central region **825** is preferably less than 50.0, more preferably between 0.10 and 30.0, more preferably between 0.50 and 30.0, even more preferably between 1.0 and 10.0, and still even more preferably between 1.00 and 5.0. In some embodiments, the aspect ratio of the central region (e.g., central region **825**) is between 0.25 and 10.0. In this embodiment, the aspect ratio of central region **825** is 0.68. As previously described, in embodiments where the width of the central region (e.g., the width W_{825}) varies depending on where it is measured, the maximum width of the central region is used to determine the ratio of the length of the central region to the diameter of the corresponding cutter element and the aspect ratio.

As best shown in the top view of cutter element **800** in FIG. **11**B (looking at cutting face **820** as viewed parallel to central axis **205**), in this embodiment, linear edges **224***a*, **224***d* generally slope toward each other moving radially along cutting region **221** from central region **825** to outer surface **812**, and linear edges **224***b*, **224***c* generally slope toward each other moving radially along relief region **222** from central region **825** to outer surface **812**. As a result, and unlike cutter element **200** previously described, cutting region **221** has a width measured perpendicular to a reference plane **828** containing central axis **205** in top view that decreases moving radially from central region **825** to outer surface **812**, and similarly, relief region **222** has a width measured perpendicular to reference plane **828** in top view that decreases moving radially from central region **825** to outer surface **812**. As best shown in the top view of cutter element **800** in FIG. **11**B (looking at cutting face **820** as viewed parallel to central axis **205**), in this embodiment, cutting face **820** is symmetric about the reference plane **828** that contains central axis **205**, is disposed between lateral regions **223***a*, **223***b*, and bisects crown **827** and regions **221**, **222**. A cutting edge **829** is defined at the intersection of cutting region **221** and chamfer **811**.

A plurality of cutting elements **800** are mounted in bit body **110** in the same manner and orientation as cutter elements **200** previously described. More specifically, each cutter element **800** is mounted to a corresponding blade **141**, **142** with substrate **201** received and secured in a pocket formed in the cutter support surface **144** of the blade **141**, **142** to which it is fixed by brazing or other suitable means. In addition, each cutter element **800** is oriented with axis **205** oriented generally parallel or tangent to cutting direction **106** and such that the corresponding cutting face **820** is exposed and leads the cutter element **800** relative to cutting direction **106** of bit **100**. Further, cutter elements **800** are oriented with corresponding planes **828** oriented perpendicular to the cutter support surface **144**, cutting region **221** distal the corresponding cutter support surface **144** (with cutting edge **829** defining the extension height of the cutter element **800**), and relief region **821** proximal the corresponding cutter support surface **144**. During drilling operations, cutting faces **820** of cutter elements **800** engage, penetrate, and shear the formation in the same manner as cutting faces **220** of cutter elements **200** previously described.

Referring now to FIGS. **12**A-**12**D, an embodiment of a cutter element **900** is shown. In general, a plurality of cutter elements **900** can be used in place of cutter elements **200** on bit **100** previously described. Cutter element **900** is substantially the same as cutter element **700** previously described with the exception of the geometry of the central region (e.g., central region **225**). Namely, cutter element **900** includes a base or substrate **201** and a cutting disc or layer **210** bonded to the substrate **201**. Substrate **201** is as previously described, and cutting layer **210** is as previously described except that central region **225** is replaced with a central region **925** having a different geometry. In particular, central region **925** has a length L_{925} measured parallel to plane **228** from edge **226***a* to edge **226***c* in top view, and a width W_{925} measured perpendicular to plane **228** from edge **226***b* to edge **226***d* in top view. Central region **925** is rectangular with linear edges **226***a*, **226***c* oriented parallel to each other and linear edges **226***b*, **226***d* oriented parallel to each other, and thus, the length L_{925} measured between edges **226***a*, **226***c* is constant at all points along edges **226***a*, **226***c*, and further, the width W_{925} measured between edges **226***b*, **226***d* is constant at all points along edges **226***b*, **226***d*. The ratio of the length L_{925} to the diameter of cutter element **900** is less than 1.0, preferably between 0.10 and 0.90, more preferably between 0.20 and 0.80, and even more preferably between 0.25 and 0.75, and still even more preferably between 0.33 and 0.66; and the aspect ratio of central region **925** is preferably less than 50.0, more preferably between 0.10 and 30.0, more preferably between 0.50 and 30.0, even more preferably between 1.0 and 10.0, and still even more preferably between 1.0 and 5.0. In some embodiments, the aspect ratio of the central region (e.g., central region **925**) is between 0.25 and 10.0. In this embodiment, the ratio of the length L_{925} to the diameter of cutter element **900** is 0.5 and the aspect ratio of central region **925** is 8.0.

A plurality of cutting elements **900** are mounted in bit body **110** in the same manner and orientation as cutter elements **200** previously described. More specifically, each cutter element **900** is mounted to a corresponding blade **141**, **142** with substrate **201** received and secured in a pocket formed in the cutter support surface **144** of the blade **141**, **142** to which it is fixed by brazing or other suitable means. In addition, each cutter element **900** is oriented with axis **205** oriented generally parallel or tangent to cutting direction **106** and such that the corresponding cutting face **220** is exposed and leads the cutter element **900** relative to cutting direction **106** of bit **100**. Further, cutter elements **900** are oriented with corresponding planes **228** oriented perpendicular to the cutter support surface **144**, cutting region **221** distal the corresponding cutter support surface **144** (with cutting edge **229** defining the extension height of the cutter element **900**), and relief region **221** proximal the corresponding cutter support surface **144**. During drilling operations, cutting faces **220** of cutter elements **900** engage, penetrate, and shear the formation in the same manner as cutting faces **220** of cutter elements **200** previously described.

Referring now to FIGS. **13**A-**13**D, an embodiment of a cutter element **1000** is shown. In general, a plurality of cutter elements **1000** can be used in place of cutter elements **200** on bit **100** previously described. Cutter element **1000** is substantially the same as cutter element **500** previously described with the exception of the geometry of the central region (e.g., central region **525**) and that flats **230***a*, **230***b* have been eliminated. In other words, in this embodiment, no planar flats are provided. Thus, in this embodiment, cutter element **1000** includes a base or substrate **201** and a cutting disc or layer **510** bonded to the substrate **201**. Base **201** is as previously described with the sole exception that no flats (e.g., flats **230***a*, **230***b*) are provided. Thus, base **201** has a central axis **205**, a first end **201***a* bonded to cutting layer **810**, a second end **201***b* distal cutting layer **810**, and a radially outer surface **202** extending axially between ends **201***a*, **201***b*. As no flats are provided, outer surface **202** is a cylindrical surface extending about the entire circumference of base **201**.

Cutting layer **510** is as previously described except that central region **525** is replaced with a central region **1025** having a different geometry. In particular, central region **1025** is a cylindrical surface disposed at a radius of curvature. As best shown in FIG. **13**D, region **1025** is a cylindrical surface disposed at a radius R_{1025} relative to an axis oriented perpendicular to reference plane **528** that contains central axis **205**, is disposed between lateral regions **223***a*, **223***b*, and bisects crown **527** and regions **221**, **222**. Similar to radius R_{525} previously described, radius R_{1025} ranges from 1.0 to 50.0 mm, and more preferably ranges from 5.0 to 20.0 mm. In this embodiment, radius R_{1025} is 45 mm.

As best shown in FIG. **13**B, in this embodiment, central region **1025** has a length L_{1025} measured parallel to plane **528** from edge **526***a* to edge **526***c* in top view, and a width W_{1025} measured perpendicular to plane **228** from edge **526***b* to edge **526***d* in top view. In this embodiment, linear edges **526***a*, **526***c* are oriented parallel to each other while non-linear edges **526***b*, **526***d* are not oriented parallel to each other. Thus, the length L_{1025} measured between edges **526***a*, **526***c* is constant at all points along edges **526***a*, **526***c*, while the width W_{1025} varies depending on where it is measured along edges **526***b*, **526***d*. The geometry of central region **1025** may be characterized by the ratio of the length L_{1025} to the diameter of cutter element **1000** and an "aspect ratio" that is equal to the ratio of the length L_{1025} to the width W_{1025}. The ratio of the length L_{1025} to the diameter of cutter element **1000** is less than 1.0, preferably between 0.10 and 0.90, more preferably between 0.20 and 0.80, and even more preferably between 0.25 and 0.75, and still even more preferably between 0.33 and 0.66; and the aspect ratio of central region **1025** is preferably less than 50.0, more preferably between 0.10 and 30.0, more preferably between 0.50 and 30.0, even more preferably between 1.0 and 10.0, and still even more preferably between 1.0 and 5.0. In some embodiments, the aspect ratio of the central region (e.g., central region **1025**) is between 0.25 and 10.0. In this embodiment, the aspect ratio of central region **1025** is 1.13. As previously described, in embodiments where the width of the central region (e.g., the width W_{1025}) varies depending on where it is measured, the maximum width of the central region is used to determine the ratio of the length of the central region to the diameter of the corresponding cutter element and the aspect ratio.

A plurality of cutting elements **1000** are mounted in bit body **110** in the same manner and orientation as cutter elements **200** previously described. More specifically, each cutter element **1000** is mounted to a corresponding blade **141**, **142** with substrate **201** received and secured in a pocket formed in the cutter support surface **144** of the blade **141**, **142** to which it is fixed by brazing or other suitable means. In addition, each cutter element **1000** is oriented with axis **205** oriented generally parallel or tangent to cutting direction **106** and such that the corresponding cutting face **520** is exposed and leads the cutter element **1000** relative to cutting direction **106** of bit **100**. Further, cutter elements **1000** are oriented with corresponding planes **528** oriented perpendicular to the cutter support surface **144**, cutting region **221** distal the corresponding cutter support surface **144** (with cutting edge **529** defining the extension height of the cutter element **1000**), and relief region **221** proximal the corresponding cutter support surface **144**. During drilling operations, cutting faces **220** of cutter elements **1000** engage, penetrate, and shear the formation in the same manner as cutting faces **220** of cutter elements **200** previously described.

While preferred embodiments have been shown and described, modifications thereof can be made by one skilled in the art without departing from the scope or teachings herein. The embodiments described herein are exemplary only and are not limiting. Many variations and modifications of the systems, apparatus, and processes described herein are possible and are within the scope of the disclosure. For example, the relative dimensions of various parts, the materials from which the various parts are made, and other parameters can be varied. Accordingly, the scope of protection is not limited to the embodiments described herein, but is only limited by the claims that follow, the scope of which shall include all equivalents of the subject matter of the claims. Unless expressly stated otherwise, the steps in a method claim may be performed in any order. The recitation of identifiers such as (a), (b), (c) or (1), (2), (3) before steps in a method claim are not intended to and do not specify a particular order to the steps, but rather are used to simplify subsequent reference to such steps.

What is claimed is:

1. A cutter element for a drill bit configured to drill a borehole in a subterranean formation, the cutter element comprising:

a base portion having a central axis, a first end, a second end, and a radially outer cylindrical surface extending axially from the first end to the second end;

a cutting layer fixably mounted to the first end of the base portion, wherein the cutting layer includes a cutting face distal the base portion and a radially outer cylindrical surface extending axially from the cutting face to the radially outer cylindrical surface of the base portion, wherein the radically outer cylindrical surface of the cutting layer is contiguous with the radially outer cylindrical surface of the base portion;

wherein the cutting face comprises:

an elongate raised ridge extending across the cutting face, wherein the raised ridge has a first end at the radially outer surface of the cutting layer and a second end at the radially outer cylindrical surface of the cutting layer, and wherein the raised ridge defines a maximum height of the cutter element measured axially from the second end of the base portion to the cutting face;

a first planar lateral side surface extending from the raised ridge to the radially outer cylindrical surface of the cutting layer; and

a second planar lateral side surface extending from the raised ridge to the radially outer cylindrical surface of the cutting layer;

wherein the raised ridge of the cutting face comprises a central surface, a cutting surface extending radially from the central surface toward the radially outer cylindrical surface of the cutting layer, and a relief surface extending radially from the central surface toward the radically outer cylindrical surface, wherein the central surface is planar;

wherein the central surface has a length L measured from a first intersection of the central surface and the cutting surface to a second intersection of the central surface and the relief surface in top view;

wherein the central surface has a width W measured from a third intersection of the central surface and the first planar lateral side surface to a fourth intersection of the central surface and the second planar lateral side surface in top view;

wherein the ratio of the length L to a diameter of the base portion is between 0.10 and 0.90; and

wherein an aspect ratio of the central surface equal to the ratio of the length L to the width W is between 0.10 and 30.0.

2. The cutter element of claim **1**, wherein each planar lateral side surface extends axially toward the base portion moving from the raised ridge toward the radially outer cylindrical surface of the cutting layer.

3. The cutter element of claim **2**, wherein each planar lateral side surface is oriented at an angle α relative to a reference plane oriented perpendicular to the central axis, wherein each angle α ranges from 5° to 25°.

4. The cutter element of claim **3**, wherein the angle α between the first planar lateral side surface and the reference plane is equal to the angle α between the second planar lateral side surface and the reference plane.

5. The cutter element of claim **1**, wherein the central surface is oriented perpendicular to the central axis.

6. The cutter element of claim **5**, wherein the central surface is radially centered on the cutting face.

7. The cutting element of claim **5**, wherein the central surface is rectangular.

8. The cutting element of claim **1**, wherein the cutting surface is planar and the relief surface is planar.

9. The cutting element of claim **8**, wherein the cutting surface is oriented at an acute angle β relative to a reference plane oriented perpendicular to the central axis, and wherein

the relief surface is oriented at an acute angle θ relative to the reference plane oriented perpendicular to the central axis, wherein the angle β ranges from 1° to 20° and the angle θ ranges from 1° to 20°.

10. The cutting element of claim **8**, wherein the cutting surface slopes axially toward the base portion moving radially outward from the central surface toward the radially outer cylindrical surface of the cutting layer and the relief surface slopes axially toward the base portion moving radially outward from the central surface toward the radially outer cylindrical surface of the cutting layer.

11. The cutting element of claim **1**, wherein the cutting surface is continuously curved and concave or convex between the central surface and the radially outer cylindrical surface of the cutting layer and the relief surface is continuously curved and concave or convex between the central surface and the radially outer cylindrical surface of the cutting layer.

12. The cutter element of claim **1**, further comprising:

a first planar flat extending from the cutting face along the radially outer cylindrical surface of the cutting layer into the radially outer cylindrical surface of the base portion;

a second planar flat extending from the cutting face along the radially outer cylindrical surface of the cutting layer into the radially outer cylindrical surface of the base portion, wherein the first planar flat and the second planar flat are circumferentially spaced part.

13. The cutter element of claim **12**,

wherein the first planar flat extends circumferentially along a portion of the first planar lateral side surface and a portion of the cutting surface;

wherein the second planar flat extends circumferentially along a portion of the second planar lateral side surface and a portion of the cutting surface.

14. The cutter element of claim **12**, wherein the first planar flat is oriented perpendicular to a first reference plane containing the central axis and the second planar flat is oriented perpendicular to a second reference plane containing the central axis;

wherein the first reference plane and the second reference plane are angularly spaced apart about the central axis by an angle μ that ranges from 70° to 120°.

15. The cutter element of claim **14**, wherein each planar flat slopes radially outward moving axially from the cutting face into the base portion.

16. The cutter element of claim **15**, wherein the first planar flat is oriented at an angle σ_1 relative to the central axis as measured in the first reference plane and the second planar flat is oriented at an angle σ_2 relative to the central axis as measured in the second reference plane, wherein the angle σ_1 ranges from 2° to 10° and the angle σ_2 ranges from 2° to 10°.

17. The cutter element of claim **16**, wherein the cutting face is symmetric about a reference plane containing the central axis and bisecting the raised ridge.

18. A cutter element for a drill bit configured to drill a borehole in a subterranean formation, the cutter element comprising:

a base portion having a central axis, a first end, a second end, and a radially outer cylindrical surface extending axially from the first end to the second end;

a cutting layer fixably mounted to the first end of the base portion, wherein the cutting layer includes a cutting face distal the base portion and a radially outer cylindrical surface extending axially from the cutting face to the radially outer cylindrical surface of the base portion, wherein the radically outer cylindrical surface of the cutting layer is contiguous with the radially outer cylindrical surface of the base portion;

wherein the cutting face comprises:

an elongate raised ridge extending across the cutting face, wherein the raised ridge has a first end at the radially outer surface of the cutting layer and a second end at the radially outer cylindrical surface of the cutting layer, and wherein the raised ridge defines a maximum height of the cutter element measured axially from the second end of the base portion to the cutting face;

a first planar lateral side surface extending from the raised ridge to the radially outer cylindrical surface of the cutting layer; and

a second planar lateral side surface extending from the raised ridge to the radially outer cylindrical surface of the cutting layer

wherein the raised ridge of the cutting face comprises a central surface, a cutting surface extending radially from the central surface toward the radially outer cylindrical surface of the cutting layer, and a relief surface extending radially from the central surface toward the radially outer cylindrical surface, wherein the cutting surface is planar and the relief surface is planar;

wherein the central surface is continuously curved and convex or concave between the cutting surface and the relief surface;

wherein the central surface has a length L measured from a first intersection of the central surface and the cutting surface to a second intersection of the central surface and the relief surface in top view;

wherein the central surface has a width W measured from a third intersection of the central surface and the first planar lateral side surface to a fourth intersection of the central surface and the second planar lateral side surface in top view;

wherein the ratio of the length L to a diameter of the base portion is between 0.10 and 0.90; and

wherein an aspect ratio of the central surface equal to the ratio of the length L to the width W is between 0.10 and 30.0.

19. The cutter element of claim **18**, wherein each planar lateral side surface extends axially toward the base portion moving from the raised ridge toward the radially outer cylindrical surface of the cutting layer.

20. The cutter element of claim **19**, wherein each planar lateral side surface is oriented at an angle α relative to a reference plane oriented perpendicular to the central axis, wherein each angle α ranges from 5° to 25°.

21. The cutter element of claim **20**, wherein the angle α between the first planar lateral side surface and the reference plane is equal to the angle α between the second planar lateral side surface and the reference plane.

22. The cutter element of claim **18**, wherein the central surface is radially centered on the cutting face.

23. The cutting element of claim **18**, wherein the central surface is rectangular.

24. The cutting element of claim **18**, wherein the cutting surface is oriented at an acute angle β relative to a reference plane oriented perpendicular to the central axis, and wherein the relief surface is oriented at an acute angle θ relative to the reference plane oriented perpendicular to the central axis, wherein the angle β ranges from 1° to 20° and the angle θ ranges from 1° to 20°.

25. The cutting element of claim **18**, wherein the cutting surface slopes axially toward the base portion moving radially outward from the central surface toward the radially outer cylindrical surface of the cutting layer and the relief surface slopes axially toward the base portion moving radially outward from the central surface toward the radially outer cylindrical surface of the cutting layer.

26. The cutter element of claim **18**, further comprising:

a first planar flat extending from the cutting face along the radially outer cylindrical surface of the cutting layer into the radially outer cylindrical surface of the base portion;

a second planar flat extending from the cutting face along the radially outer cylindrical surface of the cutting layer into the radially outer cylindrical surface of the base portion, wherein the first planar flat and the second planar flat are circumferentially spaced part.

27. The cutter element of claim **26**, wherein the first planar flat extends circumferentially along a portion of the first planar lateral side surface and a portion of the cutting surface;

wherein the second planar flat extends circumferentially along a portion of the second planar lateral side surface and a portion of the cutting surface.

28. The cutter element of claim **26**, wherein the first planar flat is oriented perpendicular to a first reference plane containing the central axis and the second planar flat is oriented perpendicular to a second reference plane containing the central axis;

wherein the first reference plane and the second reference plane are angularly spaced apart about the central axis by an angle μ that ranges from 70° to 120°.

29. The cutter element of claim **28**, wherein each planar flat slopes radially outward moving axially from the cutting face into the base portion.

30. The cutter element of claim **29**, wherein the first planar flat is oriented at an angle σ_1 relative to the central axis as measured in the first reference plane and the second planar flat is oriented at an angle σ_2 relative to the central axis as measured in the second reference plane, wherein the angle σ_1 ranges from 2° to 10° and the angle σ_2 ranges from 2° to 10°.

31. The cutter element of claim **30**, wherein the cutting face is symmetric about a reference plane containing the central axis and bisecting the raised ridge.

32. A cutter element for a drill bit configured to drill a borehole in a subterranean formation, the cutter element comprising:

a base portion having a central axis, a first end, a second end, and a radially outer cylindrical surface extending axially from the first end to the second end;

a cutting layer fixably mounted to the first end of the base portion, wherein the cutting layer includes a cutting face distal the base portion and a radially outer cylindrical surface extending axially from the cutting face to the radially outer cylindrical surface of the base portion, wherein the radically outer cylindrical surface of the cutting layer is contiguous with the radially outer cylindrical surface of the base portion;

wherein the cutting face comprises:

a planar central region;

a planar cutting region extending radially from the planar central region to the radially outer surface of the cutting layer;

a planar relief region extending radially from the planar central region to the radially outer surface of the cutting layer;

a first planar lateral side region extending laterally from the planar central region, the planar cutting region, and the planar relief region to the radially outer surface of the cutting layer; and

a second planar lateral side region extending laterally from the planar central region, the planar cutting region, and the planar relief region to the radially outer surface of the cutting layer;

wherein the first planar lateral side region slopes axially downward moving laterally from the planar central region, the planar cutting region, and the planar relief region toward the radially outer surface of the cutting layer;

wherein the second planar lateral side region slopes axially downward moving laterally from the planar central region, the planar cutting region, and the planar relief region to the radially outer surface of the cutting layer;

wherein the planar cutting region is circumferentially positioned between the first planar lateral side region and the second planar lateral side region;

wherein the planar relief region is circumferentially positioned between the first planar lateral side region and the second planar lateral side region;

wherein the planar central region is disposed between the first planar lateral side region and the second planar lateral side region;

wherein the planar central region has a length L measured from a first intersection of the planar central region and the planar cutting region to a second intersection of the planar central region and the planar relief region in top view;

wherein the planar central region has a width W measured from a third intersection of the planar central region and the first planar lateral side surface to a fourth intersection of the planar central region and the second planar lateral side surface in top view;

wherein the ratio of the length L to a diameter of the base portion is between 0.10 and 0.90; and

wherein an aspect ratio of the planar central region equal to the ratio of the length L to the width W is between 0.10 and 30.0.

33. The cutter element of claim **32**, wherein the planar central region is oriented perpendicular to the central axis.

34. The cutter element of claim **33**, wherein each planar lateral side region is oriented at an angle α relative to a reference plane oriented perpendicular to the central axis, wherein each angle α ranges from 5° to 25°.

35. The cutter element of claim **34**, wherein the angle α between the first planar lateral side region and the reference plane is equal to the angle α between the second planar lateral side region and the reference plane.

36. The cutting element of claim **34**, wherein the planar cutting region is oriented at an acute angle β relative to the reference plane and the planar relief region is oriented at an acute angle θ relative to the reference plane, wherein the angle β ranges from 1° to 20° and the angle θ ranges from 1° to 20°.

37. The cutter element of claim **32**, wherein the planar central region is radially centered on the cutting face.

38. The cutting element of claim **37**, wherein the planar central region is rectangular.

39. The cutting element of claim **32**, wherein the planar cutting region slopes axially toward the base portion moving radially outward from the central region to the radially outer surface of the cutting layer and the planar relief region slopes axially toward the base portion moving radially outward from the planar central region to the radially outer surface of the cutting layer.

40. The cutter element of claim **32**, wherein the radially outer surface of the base portion is cylindrical and the radially outer surface of the cutting layer is cylindrical.

41. The cutter element of claim **40**, further comprising:

a first planar flat extending from the cutting face along the radially outer surface of the cutting layer into the radially outer surface of the base portion;

a second planar flat extending from the cutting face along the radially outer surface of the cutting layer into the radially outer surface of the base portion, wherein the first planar flat and the second planar flat are circumferentially spaced part.

42. The cutter element of claim **41**, wherein the first planar flat extends circumferentially along a portion of the first planar lateral side surface and a portion of the planar cutting surface;

wherein the second planar flat extends circumferentially along a portion of the second planar lateral side surface and a portion of the planar cutting surface.

43. The cutter element of claim **41**, wherein the first planar flat is oriented perpendicular to a first reference plane containing the central axis and the second planar flat is oriented perpendicular to a second reference plane containing the central axis;

wherein the first reference plane and the second reference plane are angularly spaced apart about the central axis by an angle μ that ranges from 70° to 120°.

44. The cutter element of claim **43**, wherein each planar flat slopes radially outward moving axially from the cutting face into the base portion.

45. The cutter element of claim **44**, wherein the first planar flat is oriented at an angle σ_1 relative to the central axis as measured in the first reference plane and the second planar flat is oriented at an angle σ_2 relative to the central axis as measured in the second reference plane, wherein the angle σ_1 ranges from 2° to 10° and the angle σ_2 ranges from 2° to 10°.

46. The cutter element of claim **32**, wherein the cutting face is symmetric about a reference plane containing the central axis and bisecting the planar central region, the planar cutting region, and the planar relief region.

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